DELAWARE UNIV NEWARK DEPT OF CIVIL ENGINEERING NUMERICAL MODELING OF THE NEARSHORE REGION.(U) JUN 82 J T KIRBY, R A DALRYMPLE CE-82-24 AD-A118 518 F/G 8/3 N00014-81-K-0297 UNCLASSIFIED 10,2 A0 A 118516

# NUMERICAL MODELING OF THE NEARSHORE REGION

by

James T. Kirby, Jr. and Robert A. Dalrymple

Technical Report No. 11

Contract No. N00014-81-K-0297

with the OFFICE OF NAVAL RESEARCH, GEOGRAPHY PROGRAMS

Research Report CE-82-24

June 1982

OCEAN ENGINEERING PROGRAM

DEPARTMENT OF CIVIL ENGINEERING UNIVERSITY OF DELAWARE NEWARK, DELAWARE 19711

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Ocean Engineering Program

Department of Civil Engineering

University of Delaware

Newark, Delaware

19711

#### SECURITY CLASSIFICATION OF THIS PAGE (When Date Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
ONR TR. No. 11	<b>(</b>	l
4. TITLE (and Subilife)		S. TYPE OF REPORT & PERIOD COVERED
Numerical Modelling of the N	Nearshore Region	
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(*)		B. CONTRACT OR GRANT NUMBER(*)
James T. Kirby, Jr. and Robert A. Dalrymple		N00014-81-K-0297
9. PERFORMING ORGANIZATION NAME AND ADDRE	:\$5	10. PROGRAM ELÉMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE June 1982
Department of Civil Engine University of Delaware, Ne		13. NUMBER OF PAGES 163
14. MONITORING AGENCY NAME & AODRESSILL dille	rent from Controlling Office)	15. SECURITY CLASS, (of this report)
		15a. DECLASSIFICATION/OOWNGRADING SCHEDULE

This report has been approved for public release and sale; its distribution is unlimited

- 17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, If different from Report)
- 18. SUPPLEMENTARY NOTES
- 19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Numerical models, nearshore circulation, longshore currents, rip currents

# 20. ABSTRACT (Continue on severee side if necessary and identify by block number)

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SECURITY CLASSIFICATION OF THIS PAGE (From Data Entered)

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A calibration of both models is described based on comparison with field data obtained from the NSTS Torrey Pines experiment (Gable, 1979). Finally, various results obtained during previous studies utilizing the models are presented and discussed.

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P. 11, VI P. 28, 44, 76, 110, 117, 126, 142

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## Chapter I

#### INTRODUCTION

The need for methods to accurately predict the magnitude and spatial distribution of nearshore currents is central to the present research efforts aimed at quantifying the transport of marine sediment in the beach and nearshore environment. Investigators have made significant strides in describing the mean wave-induced motions in the surf zone in the twenty years since the correct formulation of the averaged equations of motion. Using the concept of wave momentum flux, or radiation stress (see Longuet-Higgins and Stewart, 1964), it has become possible to analytically predict the wave set-up, long-shore currents, and spacing of rip currents on beaches of simple planform. Recent strides have also been made towards predicting the dynamic response of the surf zone to fluctuating driving forces with time scales larger than that of the incident wind waves, such as surf boat (see, for example, Symonds, Huntley, and Bowen, 1982).

In general, however, the nearshore environment is a complex system which is not amenable to analytic treatment. Even in simple situations, the presence of a physical feature predicted by one mechanism, such as the longshore current, will greatly complicate the prediction of a separate feature, such as rip currents. In addition, the action of waves and currents on the bottom can create complex topographies, making a reduction of the analytic problems to one space dimension impossible.

This report represents a review and conclusion of several studies conducted at the University of Delaware with the aim of providing a numerical

fluctuations. The purpose of constructing a numerical model rests on the need to extend our predictive capabilities into situations which lie beyond the scope of analytic methods. In the end, all numerical models, as well as analytic formulations, are limited in scope by the simplifying assumptions incorporated in their theoretical framework; in this regard, the present models represent an attempt to extend present analytic treatments to the case of a complex topography in two dimensions. The models do not consider the associated sediment transport problem, although this capability can be added (see McDougal, 1979, and Paddock and Ditmars, 1981). Also, the models require that the incident wave field be regarded as monochromatic, or, after some model modifications, narrow banded enough to be represented as a modulated wave train at a single carrier frequency.

The models described here utilize a wave refraction scheme developed by Noda et al. (1974). Using this scheme, Birkemeier and Dalrymple (1976) developed a circulation model, referred to here as the linear model, which neglected the effect of convective accelerations and lateral mixing. The model of Ebersole and Dalrymple (1979), referred to here as the nonlinear model, extended the treatment to include these effects.

In Chapter II, the theoretical framework for the two models is described, followed by an outline of the numerical formulations in Chapter III. In Chapter IV, we present a calibration of the models using field data from the NSTS Torrey Pines experiment (Gable, 1979). Chapter V gives a summary of applications of the models presented in Birkemeier and Dalrymple (1976) and Ebersole and Dalrymple (1979).

## Chapter II

#### THEORETICAL DEVELOPMENT OF THE MODELS

#### 1. INTRODUCTION

In this chapter the theoretical framework for the development of time averaged governing equations for the problem of waves and currents in the nearshore zone is outlined. The development of the numerical circulation models in either the "linear" or "nonlinear" form is then described in Chapter III based on the theoretical framework.

In general, the development of each model has been described in previous technical reports; the linear model in Birkemeier and Dalrymple (1976), and the nonlinear model in Ebersole and Dalrymple (1979). For this reason, some of the derivations and intermediate steps needed to develop the governing equations are not described in detail in the present report. The reader can refer to the previous work for missing details. However, both models now include the option of calculating wave energy decay due to interaction with the bottom, which has not been included in previous reports. The theory and implementation of this option is described in detail.

## 2. THEORETICAL FRAMEWORK FOR THE MODELS

The basis for any fluid dynamic model rests on the principle of conservation of mass, conservation of momentum (the Navier-Stokes equations),

and conservation of energy. The resulting system of equations, together with boundary conditions which quantify the interaction of the fluid continuum with its solid and free bounding surfaces, give a mathematical representation of the physical problem of interest. The problem may then be further simplified by assumptions which are consistent with the physical processes involved.

Here, we are interested in the effect of waves propagating towards shore over a complex bathymetry and breaking, and the mean currents driven by changes in the flux of wave momentum. The problem has two apparent timescales; a fast time scale associated with the oscillation of the incident waves, and a slower time scale over which the characteristics of the incident wave, such as height and angle of incidence, may vary. The longer time scale may also include the effect of changes in wind, tidal oscillation, and, in models, which include sediment transport, gradual shift of the bottom. Since our attention here is towards mean quantities which are reasonably steady in time, the set of equations may be averaged over the faster time scale of the wave oscillation to remove the direct effect of the oscillation. The effect of the waves then is represented by a stress-like term acting on the slowly varying mean flow pattern. In addition, since we are mainly interested in net transport quantities rather than detailed structure of the velocity profiles over depth, the equations may be averaged over depth, reducing the entire problem to a two dimensional problem in the horizontal plane together with appropriate boundary conditions. This averaged model can then be solved using numerical procedures, as discussed in Chapter III. The quantities to be determined are: the horizontal components of mean wave-induced current,

the local wave height and angle of incidence, and the set-up, or wave-induced deviation of the mean water surface from its still-water level.

# 2.1 Specification of the Boundary Value Problem

A right-handed coordinate system is defined with x in the offshore direction, normal to the coastline, y in the longshore direction, and z vertically upward (see Figure 1). The continuity equation is

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y} + \frac{\partial (\rho w)}{\partial z} = 0$$
 (2.1)

where  $\rho$  is the water density and (u,v,w) are the (x,y,z) components of velocity, respectively. The continuity equation can be further reduced to the form

$$\frac{\partial \mathbf{u}}{\partial \mathbf{x}} + \frac{\partial \mathbf{v}}{\partial \mathbf{y}} + \frac{\partial \mathbf{w}}{\partial \mathbf{z}} = 0 \tag{2.2}$$

consistent with an assumption of constant water density p.

The momentum equations are, in the x direction

$$\frac{\partial \mathbf{u}}{\partial \mathbf{t}} + \frac{\partial \mathbf{u}^2}{\partial \mathbf{x}} + \frac{\partial \mathbf{u}\mathbf{v}}{\partial \mathbf{y}} + \frac{\partial \mathbf{u}\mathbf{w}}{\partial \mathbf{z}} = -\frac{1}{\rho} \frac{\partial \mathbf{P}}{\partial \mathbf{x}} + \frac{1}{\rho} \left\{ \frac{\partial \tau}{\partial \mathbf{x}} + \frac{\partial \tau}{\partial \mathbf{y}} + \frac{\partial \tau}{\partial \mathbf{z}} \right\} , \qquad (2.3)$$

in the y direction,

$$\frac{\partial \mathbf{v}}{\partial t} + \frac{\partial \mathbf{u} \mathbf{v}}{\partial \mathbf{x}} + \frac{\partial \mathbf{v}^2}{\partial \mathbf{y}} + \frac{\partial \mathbf{v} \mathbf{w}}{\partial \mathbf{z}} = -\frac{1}{\rho} \frac{\partial \mathbf{P}}{\partial \mathbf{y}} + \frac{1}{\rho} \left\{ \frac{\partial \tau_{\mathbf{x} \mathbf{y}}}{\partial \mathbf{x}} + \frac{\partial \tau_{\mathbf{y} \mathbf{y}}}{\partial \mathbf{y}} + \frac{\partial \tau_{\mathbf{z} \mathbf{y}}}{\partial \mathbf{z}} \right\} , \qquad (2.4)$$

and in the z direction,

$$\frac{\partial w}{\partial t} + \frac{\partial uw}{\partial x} + \frac{\partial vw}{\partial y} + \frac{\partial w^2}{\partial z} = -\frac{1}{\rho} \frac{\partial}{\partial z} \left( P + gz \right) + \frac{1}{\rho} \left( \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} \right), \quad (2.5)$$

after substitution of the continuity equation into the convective acceleration terms.

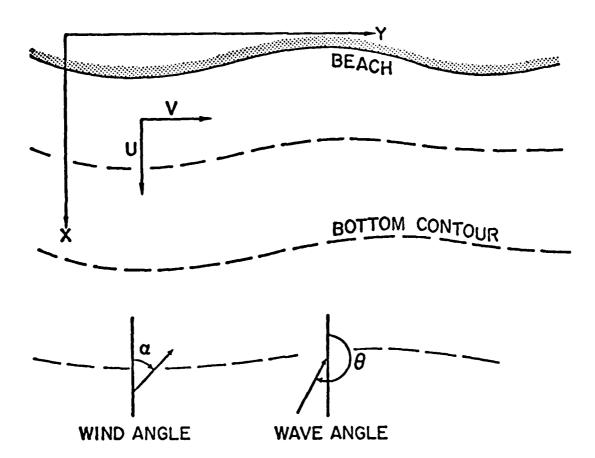


Figure 2-1. Plan Definition Sketch For Coordinate System.

## Boundary Conditions

Certain boundary conditions are required at the physical boundary of the water body in question in order to correctly specify the problem. First, kinematic conditions are specified at the free surface and rigid bottom, which state that water particles may not cross the boundary surface, whether it be rigid or moving.

The equation of a surface of the fluid domain is given by

$$F(x,y,z,t) = 0 .$$

A water particle cannot flow across the surface, otherwise the surface would cease to exist. Mathematically, this condition is expressed by the total time rate of change of the function F(x,y,z,t) being equal to zero.

$$\frac{D}{Dt} (F(x,y,z,t)) = 0 .$$

At the free surface the boundary is given by

$$F_1(x,y,z,t) = z - \eta(x,y,t) = 0$$

and at the bottom

$$F_2(x,y,z,t) = z + h(x,y,t) = 0$$
.

Therefore, for the kinematic free surface boundary condition (KFSBC),

$$\frac{\partial F_1}{\partial t} + u \frac{\partial F_1}{\partial x} + v \frac{\partial F_1}{\partial y} + w \frac{\partial F_1}{\partial z} = 0 \qquad z = \eta$$

or

$$\frac{\partial \eta}{\partial t} + u_{\eta} \frac{\partial \eta}{\partial x} + v_{\eta} \frac{\partial \eta}{\partial y} - w_{\eta} = 0 \qquad (2.6)$$

For the bottom boundary condition (BBC) we get,

$$\frac{\partial \mathbf{h}}{\partial \mathbf{t}} + \mathbf{u}_{-\mathbf{h}} \frac{\partial \mathbf{h}}{\partial \mathbf{x}} + \mathbf{v}_{-\mathbf{h}} \frac{\partial \mathbf{h}}{\partial \mathbf{y}} + \mathbf{w}_{-\mathbf{h}} = 0$$
 (2.7)

where u,v,w are the velocity components in the x,y and z directions and the subscripts denote the evaluation of a specific term at the bottom, z = -h, or at the free surface,  $z = \eta$ .

In addition to the kinematic free surface boundary condition, a dynamic free surface boundary condition is required as well, which states that

$$P = constant$$
  $z = \eta$ 

This condition is satisfactory if we neglect the local generation of waves by wind or the deformation of the free surface due to barotropic effects. Then, using Bernoulli's equation expanded to the free surface, we obtain

$$-\frac{\partial \phi_{\eta}}{\partial t} + \frac{(u_{\eta}^{2} + v_{\eta}^{2} + w_{\eta}^{2})}{z} + g\eta = 0 \qquad z = \eta$$
 (2.8)

after setting P=0, where  $\phi(x,y,z,t)$  is the velocity potential for the wave motion.

The model also requires lateral boundary conditions. In the y (longshore) direction, the bathymetry, given by the surface h(x,y) will be required to be periodic. Since the offshore wave conditions will be assumed uniform, lateral periodicity conditions for wave and currents are also assumed.

Offshore in the x direction, the usual boundary condition for a wave problem would be to assume that all waves at the boundary other than the

incident wave are propagating away from shore, the radiation condition (Sommerfeld (1949)). However, the circulation model does not directly calculate an actual wave field. Rather, a somewhat arbitrary condition,

u = 0; x = furthest offshore grid

is imposed, which serves to put a bound on the horizontal extent of the flow under consideration.

Specification of an onshore boundary condition is an uncertain task, due to the complexity of the surf zone. In general, it is likely that some wave energy survives the breaking process and reflects from the beach, leading to waves propagated back into the region of the model. However, it is assumed for the purpose of modelling that all wave energy decays in the surf zone, reducing the wave height to a value of zero at the shoreline. In addition, both u and v are set equal to zero at the shoreline.

# 2.2 Depth and Time Averaged Forms of the Equations

By integrating the equations of motion and continuity over depth and substituting the boundary conditions, the problem is reduced to equations in two horizontal dimensions, with lateral boundary conditions prescribed.

Secondly, the quantities of principal interest are average in nature, i.e., mean currents, wave height and wave angle, and mean water level. The equations can then be time averaged over a wave period to remove consideration of instantaneous wave induced motions. The quantities remaining would be free to vary slowly in time in response to changing offshore conditions.

Integrating Eq. (2.2) over depth from z = -h(x,y,t) to  $z = r_1(x,y,t)$ , using Leibnitz rule (Hildebrand (1976), p. 365) to remove partial derivatives from within the integrals, and substituting Eqs. (2.5) and (2.6), the continuity equation becomes

$$\frac{\partial}{\partial t} \int_{h}^{n} \rho dz + \frac{\partial}{\partial x} \int_{-h}^{n} \rho u dz + \frac{\partial}{\partial y} \int_{-h}^{n} \rho v dz = 0$$
 (2.9)

Let both u and v be comprised of a time independent mean flow and a wave induced flow.

$$u = \overline{U} + \hat{u}$$

$$v = \overline{V} + \hat{v} .$$

By substituting the above expressions for u and v into Eq. (2.7) and time averaging over one wave period so as to eliminate the wave induced fluctuations, the continuity equation can be written as

$$\frac{\partial}{\partial t} \left\{ \rho \left( h + \overline{\eta} \right) \right\} + \frac{\partial}{\partial x} \left\{ \rho \overline{U} \left( h + \overline{\eta} \right) \right\} + \frac{\partial}{\partial x} \int_{-h}^{\eta} \rho \hat{u} dz$$

$$+ \frac{\partial}{\partial y} \left\{ \rho \overline{V} \left( h + \overline{\eta} \right) \right\} + \frac{\partial}{\partial y} \int_{-h}^{\eta} \rho \hat{v} dz = 0 \qquad (2.10)$$

where the symbol "\_\_\_\_ " denotes the time average over one wave period and  $\bar{n}$  the time independent mean free surface displacement. Note that the time averages of the vertically integrated wave induced velocities  $\hat{u}$  and  $\hat{v}$  are not zero.

Defining 
$$V = \overline{V} + \tilde{v}$$
,  $V = \overline{V} + \tilde{v}$ ,

where 
$$\tilde{u} = \frac{\int_{-h}^{\eta} \rho \hat{u} dz}{\rho (h + \bar{\eta})}$$
 and  $\tilde{v} = \frac{\int_{-h}^{\eta} \rho \hat{v} dz}{\rho (h + \bar{\eta})}$ 

are the wave induced mass transport velocities, and substituting the total depth D for  $(h + \overline{\eta})$ , the time averaged, depth integrated continuity equation is, in its final form

$$\frac{3\overline{\eta}}{\partial t} + \frac{3}{3x} (UD) + \frac{3}{3y} (VD) = 0 \qquad . \tag{2.11}$$

Inherent in the derivation are the assumptions that the bottom is constant with time and the density is constant in space and time.

# Momentum Equations

The x and y momentum equations are manipulated in the same way as the continuity equation in order to achieve equations which are independent of wave induced oscillations, i.e., they are integrated over depth and time averaged over a wave period. Details of this derivation may be found in Ebersole and Dalrymple (1979). The resulting equations are equivalent to those given by Phillips (1977), but are written explicitly in terms of depth averaged mean velocities. The equations contain terms for mean bottom shear stress, mean surface shear stress due to wind, mean lateral friction (not used in the linear model), and excess mean momentum stress due to wave action (the radiation stress, see Longuet-Higgins and Stewart (1964)). The x momentum equation in its final form can be written as,

$$\frac{\partial}{\partial t} (UD) + \frac{\partial}{\partial x} (U^2D) + \frac{\partial}{\partial y} (UVD) = -gD \frac{\partial \overline{\eta}}{\partial x} - \frac{D}{\rho} \frac{\partial \tau_{\ell}}{\partial y}$$
$$- \frac{1}{\rho} \frac{\partial S_{xx}}{\partial x} - \frac{1}{\rho} \frac{\partial S_{xy}}{\partial y} + \frac{1}{\rho} \frac{\overline{\tau}_{xx}}{\partial x} - \frac{1}{\rho} \frac{\overline{\tau}_{bx}}{\partial x}$$
(2.12)

and the final form of the y momentum equation can be written as

$$\frac{\partial}{\partial t} (VD) + \frac{\partial}{\partial x} (UVD) + \frac{\partial}{\partial y} (V^2D) = -gD \frac{\partial \tau}{\partial y} - \frac{D}{\rho} \frac{\partial \tau}{\partial x}$$
$$- \frac{1}{\rho} \frac{\partial S_{xy}}{\partial x} - \frac{1}{\rho} \frac{\partial S_{yy}}{\partial y} + \frac{1}{\rho} \frac{\tau}{\tau_{sy}} - \frac{1}{\rho} \frac{\tau_{by}}{\tau_{by}} . \tag{2.13}$$

# Wave Energy Equation

Following Phillips (1977), an equation expressing the conservation of averaged wave energy may be written as

$$\frac{\partial E}{\partial t} + \frac{\partial}{\partial x} \left\{ E(U + C_g \cos \theta) \right\} + \frac{\partial}{\partial y} \left\{ E(V + C_g \sin \theta) \right\}$$

$$+ S_{xx} \frac{\partial U}{\partial x} + S_{xy} \left( \frac{\partial V}{\partial x} + \frac{\partial U}{\partial y} \right) + S_{yy} \frac{\partial V}{\partial y} = \varepsilon$$
(2.14)

Here,  $\mathbf{C}_{\mathbf{g}}$  is the wave group velocity and  $\theta$  is the local wave angle. The quantity  $\epsilon$  represents the dissipation of wave energy, and is identically zero in a conservative wave field. It can be given a non-zero value to include the effect of wave damping, as described below.

#### 2.3 Radiation Stresses

The radiation stresses included in Eqs. (2.12), (2.13) and (2.14) represent the stress on the water column induced by wave action. Neglecting the effects of small scale turbulent velocities, the stresses have been given in simple form by Longuet-Higgins and Stewart (1964) as

$$S_{xx} = E [(2n - 1/2)\cos^2\theta + (n - 1/2)\sin^2\theta]$$
 (2.15)

$$S_{yy} = E [(2n - 1/2)\sin^2\theta + (n - 1/2)\cos^2\theta]$$
 (2.16)

$$S_{xy} = S_{yx} = \frac{E}{2} \text{ n sin (20)}$$
 (2.17)

where E is the wave energy,  $\theta$  is the wave angle, and n = ratio of group velocity (C<sub>g</sub>), to wave celerity (C). To second order for a progressive small amplitude wave, E and n are given by

$$E = \frac{1}{8} \rho g H^2$$
 (2.18)

$$n = \frac{c_g}{c} = \frac{1}{2} \left[ 1 + \frac{2kh}{\sinh(2kh)} \right]$$
 (2.19)

 $k = \text{wave number } (= \frac{2\pi}{L})$ 

h = depth

L = wave length

H = wave height.

#### 2.4 Wind Stress

Although other methods exist for computing the surface stress due to the wind (see Wu (1968)), the one suggested in the Shore Protection Manual (1977) has been utilized. This form was first developed by Van Dorn (1953) and gives a fairly good fit to the existing experimental data. The form of the surface stress is quadratic in the wind speed and is given by

$$\overline{\tau}_{SX} = \rho K |W| W_{X} \tag{2.20}$$

$$\overline{\tau}_{SV} = \rho K |W| W_{V}$$
 (2.21)

where W is the wind speed, and  $W_x$ ,  $W_y$  are wind velocity components in the x and y directions, as determined by the wind angle,  $\alpha$ .

The wind stress coefficient K is determined empirically to be dependent on the magnitude of the wind velocity such that

$$K = \begin{cases} K_1 & W + W_{cr} \\ K_1 + K_2 (1 + W_{cr}/W)^2 & W + W_{cr} \end{cases}$$
 (2.22)

and

$$K_1 = 1.1 \times 10^{-6}$$
 ;  $K_2 = 2.5 \times 10^{-6}$ 

$$W_{er} = 7.2 \text{ meters/second}$$

A comparison of the wind stress coefficient given here with experimental data is given in Pearce (1972).

### 2.5 Bottom Stress

The correct method for specifying the effect of a rigid bottom on waves and currents is still a matter of lively debate. For the purpose of modelling hydrodynamics in the nearshore zone, the average bottom shear stress,  $\tau_b$ , is generally taken to be of the form

$$\overline{\tau_b} = \rho \, \frac{f}{8} \, \overline{u_b | u_b |} \tag{2.23}$$

where f is a Darcy-Weisbach friction factor and  $\mathbf{u}_{b}$  is the total instantaneous scalar velocity at the bottom (Longuet-Higgins (1970a)). This relation is known as a quadratic friction law. The components of shear stress in the x and y directions can be given quite generally by (Liu and Dalrymple (1978))

$$\frac{\tau_{\text{bx}}}{\tau_{\text{bx}}} \approx \frac{\rho f}{16\pi} \int_{0}^{2\pi} (U + u_{\text{m}} \cos \theta \cos \sigma t) \cdot |\overline{u_{\text{b}}}| d(\sigma t) \qquad (2.24)$$

$$\frac{1}{\tau_{\text{by}}} \approx \frac{\rho f}{16\pi} \int_{0}^{2\pi} (V + u_{\text{m}} \sin \theta \cos \sigma t) \cdot |\overline{u_{\text{b}}}| d(\sigma t)$$
 (2.25)

where  $\boldsymbol{u}_{m}$  is the maximum wave orbital velocity given by

$$u_{\rm m} = \frac{3H}{2 \sinh kh} \tag{2.26}$$

and  $\overline{u_b}$  is the vector velocity at the bottom. The nonlinear model of Ebersole and Dalrymple (1979) retains these forms, where the integration is approximated by a 16 term Simpson's rule summation.

The linear model retains the form originally used by Birkemeier and Dalrymple (1976). For this form, the assumption that friction is primarily due to the influence of the wave orbital velocity is used. Making a small mean-current assumption, LeBlond and Tang (1974) show that the bottom stress is anisotropic, with

$$\overline{\tau_{\rm bx}} = \frac{\rho f}{2\pi} u_{\rm m} U \tag{2.27}$$

$$\overline{\tau_{\text{bv}}} = \frac{\rho f}{4\pi} u_{\text{m}} V \quad , \tag{2.28}$$

with U, V,  $u_m$ , and f as previously defined. A derivation of these equations is given in Birkemeier and Dalrymple (1976), Appendix A.

# 2.6 Wave Refraction and Shoaling Including Wave-Current Interation

The equations which govern both wave refraction and shoaling as a result of wave-current interaction used in the model are those of Noda et al. (1974). The advantage of Noda's method is that it can predict the wave angles and wave heights at certain points rather than along a wave ray. This procedure lends itself well to use in the finite difference model because calculations are performed at points which lie in the center of rectangular grid elements which are part of a larger grid mesh.

Starting with a progressive linear gravity wave, the free surface can be written as,

$$\eta(x,y,t) = a(x,y,t)\cos\{\varphi(x,y,t)\}$$

where a is the wave amplitude and  $\phi$  is a phase function. A wave number vector can be defined as

$$\vec{k} = \nabla \phi \tag{2.29}$$

and a wave scalar frequency can be defined as

$$\overline{\sigma} = -\frac{\partial \phi}{\partial t} \tag{2.30}$$

Using the mathematical property that the curl of a gradient is identically zero, it is shown that

$$\nabla \times \nabla \Phi = 0$$

which implies that

$$\nabla x \overrightarrow{k} = 0$$

This equality states that the wave number vector is irrotational. Assuming  $\phi(x,y,t)$  is continuous, then

$$\frac{\partial}{\partial t} (\nabla \phi) = \nabla \frac{\partial \phi}{\partial t} .$$

On substituting Eqs. (2.29) and (2.30) into the above expression, it is found that

$$\frac{\partial \vec{k}}{\partial t} + \nabla \overline{\sigma} = 0 \tag{2.31}$$

which is the classical conservation of waves equation.

For the case of a wave propagating on a current with velocity  $\ddot{u}=u\ddot{i}+v\ddot{j}$ , it can be shown that the scalar frequency with respect to a stationary reference frame is

$$\tilde{x} = x + k \cdot \tilde{U} .$$

The wave frequency with respect to a moving reference frame is given by the dispersion relation,

$$\sigma^2 = gk \tanh kh \qquad (2.32)$$

If it is also assumed that the wave number field is constant in time then, from Eq. (2.31),

$$\nabla(\sigma + \vec{k} \cdot \vec{U}) = 0$$

or

$$\sigma + \vec{k} \cdot \vec{U} \approx constant$$
 . (2.33)

This constant can be evaluated for the case where  $\vec{U}$  = 0 in which case  $\sigma = \frac{2\pi}{T}$  where T is the wave period. Eq. (2.33) then becomes

$$\sigma + \vec{k} \cdot \vec{U} = \frac{2\pi}{T} \quad . \tag{2.34}$$

Using the coordinate system shown in Figure 1 and expanding Eqs. (2.29) and (2.34) into Cartesian coordinates and using the dispersion relation, the equations which govern wave refraction through wave-current interaction are given by

$$\cos \theta \left\{ \frac{\partial \theta}{\partial x} - \frac{1}{k} \frac{\partial k}{\partial y} \right\} + \sin \theta \left\{ \frac{\partial \theta}{\partial y} + \frac{1}{k} \frac{\partial k}{\partial x} \right\} = 0$$
 (2.35)

$$\{gk \tanh(kh)\}^{1/2} + Uk \cos \theta + Vk \sin \theta = \frac{2n}{T}$$
 (2.36)

where  $\theta$ , k, h, U and V are all functions that may vary in both the x and y directions.

The shoaling of waves is also affected by the interaction of waves and currents. The effect on the waves is determined by solving the energy equation. Dividing Eq. (2.14) by E and expanding in Cartesian coordinates, we get

$$\begin{split} &\frac{1}{E}\frac{\partial E}{\partial t} + (U + C_g \cos \theta) \frac{1}{E}\frac{\partial E}{\partial x} + (V + C_g \sin \theta) \frac{1}{E}\frac{\partial E}{\partial y} \\ &+ \frac{\partial}{\partial x} (U + C_g \cos \theta) + \frac{\partial}{\partial y} (V + C_g \sin \theta) \\ &+ \frac{1}{E} \left\{ S_{xx} \frac{\partial U}{\partial x} + S_{xy} \frac{\partial U}{\partial y} + S_{yy} \frac{\partial V}{\partial y} + S_{xy} \frac{\partial V}{\partial y} \right\} = \frac{\varepsilon}{E} \quad . \end{split}$$

Using this result, carrying out the differentiation, and letting a quantity Q be defined as

$$Q = \frac{1}{E} \left\{ S_{xx} \frac{\partial U}{\partial x} + S_{xy} \frac{\partial U}{\partial y} + S_{xy} \frac{\partial V}{\partial x} + S_{yy} \frac{\partial V}{\partial x} \right\}$$

the energy equation becomes,

$$\frac{2}{H}\frac{\partial H}{\partial t} + (U + C_g \cos \theta) \frac{2}{H}\frac{\partial H}{\partial x} + (V + C_g \sin \theta) \frac{2}{H}\frac{\partial H}{\partial y} + \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y}$$

$$- C_g \sin \theta \frac{\partial \theta}{\partial x} + \cos \theta \frac{\partial C_g}{\partial x} + C_g \cos \theta \frac{\partial \theta}{\partial y} + \sin \theta \frac{\partial C_g}{\partial y} + Q = \frac{\varepsilon}{E} . (2.37)$$

For all applications of the model the wave height H is assumed constant in time, so  $\frac{\partial H}{\partial t} = 0$ . From linear wave theory the group velocity  $C_g$  is given by

$$C_g = \frac{C}{2} \left\{ 1 + \frac{2kh}{\sinh(2kh)} \right\}$$

where

$$C = \left\{\frac{g}{k} \tanh(kh)\right\}^{1/2}$$

is the wave speed or celerity, k is the wave number, and h is the water depth.

#### 2.7 Wave Breaking Criteria

Since Eq. (2.37) is applicable only in determining the wave heights of nonbreaking waves, some method is needed to determine the point of breaking and the wave heights after breaking. Though a number of formulas for doing this have been developed, there is not as yet one which is universally applicable or accepted. The choice of a breaking criteria, although somewhat arbitrary, must be made with care since it determines the width of the surf zone and thus controls the set-up. The simplest breaking criteria is that predicted by solitary wave theory.

$$\left(\frac{H}{D}\right)_{b} = \text{constant} = .78 \tag{2.38}$$

where the subscript, b, denotes the value at breaking. There is, however, considerable evidence (Weggel, 1972) that this is an oversimplification.

Noda et al. (1974) used a modified version of the Miche formula

$$\left(\frac{H}{L}\right)_b = .12 \tanh \left(\frac{D}{L}\right)_b$$
 (2.39)

both to predict the point of breaking and the decay of the wave after breaking. This was done by calculating both a wave height from Eq. (2.37) and a breaking height from Eq. (2.39). When the point was reached where the wave height was

equal to or greater than the breaking height, the wave was considered to have broken and the wave height from Eq. (2.39) was used. Eq. (2.39) is used in both models to determine broken wave heights.

# 2.8 Lateral Mixing

The non-linear model of Ebersole and Dalrymple (1979) includes the effect of the lateral shear stress terms

$$\frac{-D}{\rho} \frac{\partial \overline{\tau}_{\ell}}{\partial y} , \frac{-D}{\rho} \frac{\partial \overline{\tau}_{\ell}}{\partial x}$$

in the x and y momentum equations (2.12) and (2.13) respectively. The need for these terms is pointed out by Longuet-Higgins (1970a) in his treatment of the longshore currents due to obliquely incident waves on a plane beach. Neglecting the effects of lateral shear stresses led to prediction of a longshore current distribution with a discontinuity at the breaker line and no current outside the surf zone. However, physical observation in both the laboratory and field indicate that mean longshore flows are present beyond the breaker line. Longuet-Higgins (1970b) presented a formulation which included the effect of lateral mixing as the means for handling the effect of lateral shear; the shear stresses are thus based on turbulent Reynolds stresses proportional to the local gradient of the mean velocity. The resulting velocity distributions have no discontinuity at the breaker line, and the peak velocities are shifted shoreward of the breaker line. Figure 2-2 shows a comparison of a theoretical velocity profile to one without lateral mixing included.

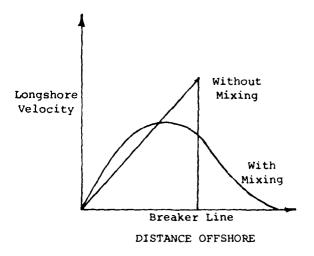


Figure 2-2 Longuet-Higgins' Analytical Solution for Oblique Wave Attack on a Plane Beach

Following the derivation of Longuet-Higgins (1970b), the lateral shear stress is written as

$$\tau_{\ell} = -\rho \left( c_{y} \frac{\partial U}{\partial y} + \epsilon_{x} \frac{\partial V}{\partial x} \right) \tag{2.40}$$

Longuet-Higgins argued that the mixing coefficient  $\frac{\varepsilon}{x}$  must tend to zero as the shoreline was approached since the turbulent eddies responsible for mixing cannot be of a scale greater than the distance to shore. He assumed that  $\varepsilon_{x}$  is proportional to the distance offshore, x, multiplied by some velocity scale which he chose to be  $\sqrt{gh}$ , the speed of a wave in shallow water where h is the local water depth. Therefore,  $\varepsilon_{x}$  can be written as

$$\varepsilon_{x} = Nx \sqrt{gh}$$

where N is a dimensionless constant whose limits Longuet-Higgins gave as

$$0 \le N \le 0.016$$

In this model the coefficient,  $\varepsilon_{_{\mathbf{X}}}$ , was allowed to vary linearly with x to some value around the breaker line. From this point seaward the coefficient remained at this constant value. The reason for this approximation is that physically there must be some limit on the scale of these eddies. This limit is at present not known. The coefficient,  $\varepsilon_{_{\mathbf{Y}}}$ , was chosen to be constant. The values of N and  $\varepsilon_{_{\mathbf{Y}}}$  are chosen during the calibration of the model.

# 2.9 Wave Height Decay

In all applications of the circulation model to date, calculation of wave parameters has been confined to a region within several wavelengths of the shore. Over this distance, wave energy decay due to interaction with the bottom is not likely to be significant, except possibly in the case of waves propagating over a soft mud bottom (Dalrymple and Liu (1978)), which is not treated here. However, the circulation model could reasonably be used to model propagation over much longer offshore extents of shallow coastal waters. At some point, the accumulated effects of bottom interaction would result in wave height reductions of a significant degree. In order to accurately model the amount of wave energy available for driving currents and maintaining mean water level variations, it is necessary to include the effects of various dissipation mechanisms in the equation for calculating wave height (2.37).

Ebersole and Dalrymple (1979) included in the nonlinear computer model, but did not describe, the option to calculate wave energy dissipation due to viscous shear in the bottom boundary layer, and due to the effect of "pumping" of water through the permeable sand bottom due to wave induced pressure

gradients at the water-bottom interface. At present, the option of calculating wave energy decay due to both mechanisms is included in both the linear and nonlinear model.

The application of wave damping to the nearshore circulation model has been described by McDougal (1979), who included the energy dissipation rate  $\epsilon$  in Eq. (2.14) in a sediment transport model based on the linear wave-current interaction model. The derivation of  $\epsilon$  is based on Liu (1973). Let  $\epsilon$  be given by

$$\varepsilon = \varepsilon_{p} + \varepsilon_{\tilde{f}} \tag{2.41}$$

where  $\varepsilon_p$  is the dissipation rate due to the permeability of the bottom, and  $\varepsilon_f$  is the dissipation rate due to bottom friction. The two effects are treated separately.

Liu (1973) solved the linear problem for waves over a porous bed of infinite depth. If the wave amplitude  $a(x,y,t)=\frac{H}{2}(x,y,t)$  is assumed to be a slowly varying function of the form

$$a(x,y,t) = a_0 e^{-\alpha t}$$
,

Liu's solution leads to the following form for  $\alpha$ ;

$$x = \frac{kg}{2|\cosh kh + (\frac{\sigma}{Q}) \sinh kh|^2} \left( \frac{v}{K_p} \frac{1}{|Q|^2} + \sqrt{\frac{v}{2\sigma}} \frac{k}{\sigma} \left| \frac{i\sigma}{Q} \right|^2 \right)$$
 (2.42)

where Q is given by

$$Q = \frac{i\sigma}{p_0} - \frac{v}{K_p}$$
 (2.43)

and

$$K_p$$
 = bed permeability  $\approx 10^{-10} \text{ M}^2$   
 $P_o$  = bed porosity  $\approx 0.6$   
 $V_o$  = kinematic viscosity  $\approx$ 

For these values of  $K_p$ ,  $P_o$ , and  $\nu$ , the viscosity term in Q is dominant, and  $\alpha$  may be reduced to the form

$$\alpha = \frac{gk}{2 \cosh^2 kh} \frac{k_p}{v}$$
 (2.44)

The dissipation rate  $\alpha$  is related to  $\epsilon_{_{D}}$  by

$$\varepsilon_{\rm p} = \frac{\partial E}{\partial t} = -2\alpha E$$

giving

$$\varepsilon_{\rm p} = -\frac{\rm gkE}{\cosh^2 \rm kh} \frac{\rm K_{\rm p}}{\rm v} \tag{2.45}$$

The rate of energy dissipation due to bottom friction,  $\boldsymbol{\varepsilon}_f$  , is given by

$$\varepsilon_{f} = (\overline{\tau_{b}} \cdot \overline{y}) A_{b}$$
 (2.46)

where  $A_{b}$  is the bed surface area.

Substituting for  $\tau_b$  and U using results derived in the absence of a mean current, we obtain the form

$$\varepsilon_{\mathbf{f}} = -\frac{\rho \mathbf{f}}{6\pi} \left(\mathbf{u}_{\mathbf{m}}\right)^3$$

where  $\mathbf{u}_{m}$  is the maximum wave induced velocity at the bottom, given by (2.26).

After some manipulation, we obtain the form

$$\varepsilon_{f} = -\frac{k}{6\pi} \frac{\sigma f H}{(\cosh kh - \cosh kh)} \cdot E$$
 (2.47)

The total energy dissipation including the effects of the porous bottom and friction is given by

$$\varepsilon = \varepsilon_{p} + \varepsilon_{f}$$

$$= -\left\{ \frac{g k}{\cosh^{2} kh} \frac{k}{v} + \frac{\sigma k f H}{6\pi (\cosh^{3} kh - \cosh kh)} \right\} \cdot E \qquad (2.48)$$

The option of including these effects is available in both forms of the numerical model presented here.

#### 3. AN OVERVIEW OF THE LINEAR AND NONLINEAR MODELS

While both of the numerical models described in Chapter III are based on the theory outlined in the previous section, each model contains a somewhat different subset of the overall development. In this section, we review the differences and similarities between the models before going on to their numerical formulation.

The intent of both of the models is to solve for the mean values U, V, and  $\eta$  at each grid point by solving the time and depth averaged equations of continuity (2.11) and momentum (2.12-13). Each model utilizes the refraction scheme of Noda et al. (1974), as represented by (2.35-37), to solve for wave angle and wave height. The model of Birkemeier and Dalrymple (1976) treats linearized forms of Eqs. (2.12-13), obtained by dropping the convective acceleration terms

$$\frac{\partial}{\partial \mathbf{x}}$$
 (U<sup>2</sup>D) ;  $\frac{\partial}{\partial \mathbf{v}}$  (UVD)

from the x-momentum equation, and the terms

$$\frac{\partial}{\partial x}$$
 (UVD) ;  $\frac{\partial}{\partial y}$  (V<sup>2</sup>D)

from the y-momentum equation. The model of Ebersole and Dalrymple (1979) retains the full nonlinear form of the momentum equations, leading to the principle theoretical difference between the models as well as explaining the distinction expressed by their names. The mathematical differences in the governing equations also lead to the requirement of significantly different numerical schemes, discussed in Chapter III.

The momentum equations contain various forcing terms which are formulated as stresses or stress gradients; these include radiation, surface and bottom stresses and a lateral stress representing the effect of turbulent mixing. The models treat radiation stresses and surface wind stresses identically. The linear model treats bottom stress according to a "weak current" formulation developed by LeBlond and Tang (1974), based on the assumption that the stress develops principally in response to the wave orbital motion. The nonlinear model uses a more exact bottom stress formulation, making no assumption as to the relative magnitude of wave orbital and mean current velocities. This distinction between the models is more historical than essential; the linear model can be updated to include the more exact relation given by Eqs. (2.24) and (2.25). This modification has been used by Allender et al. (1981) in a version of the linear model described here. A further possibility would be to represent the bottom friction using a "large-current"

formulation developed by Liu and Dalrymple (1978); this extension has not been investigated.

The remaining distinction between the models stems from the neglect of the "lateral mixing" terms Eqs. (2.12-13)

$$\frac{-p}{x} \frac{\partial \overline{v}}{\partial y} \quad ; \quad \frac{-p}{x} \frac{\partial \overline{v}}{\partial x}$$

in the linear model, and their inclusion in the nonlinear model. This difference is again historical rather than essential; these terms could be included in a modified version of the linear model, although their inclusion would require more effort than the bottom friction modification discussed above. No investigation of the effect of including lateral mixing in the linear model has been made to date.

#### Chapter III

#### FORMULATION OF THE NUMERICAL MODELS

#### 1. INTRODUCTION

In the previous chapter a mathematical formulation of the governing equations and associated boundary conditions for the problem of nearshore wave-induced circulation has been outlined. In this chapter, the numerical formulations of the mathematical model are reviewed, corresponding to the work of Birkemeier and Dalrymple (1976) and Ebersole and Dalrymple (1979).

The two models reviewed shall be referred to as the "linear model" and the "nonlinear model." The models contain significant differences as well as significant similarities in their numerical formulation as well as in their underlying mathematical formulation. Differences in the models will be discussed below following a review of the overall structure common to both models.

Both models reviewed here are finite-difference approximations to a set of three first order hyperbolic differential equations consisting of the continuity equation (2.11) and the x and y direction momentum equations (2.12, 2.13), with associated unknowns U(x,y,t), V(x,y,t) and  $\overline{\psi}(x,y,t)$ . The quantities of wave height H(x,y,t) and wave angle  $\psi(x,y,t)$  are solved for using the refraction scheme Eq. (2.35) and the wave energy equation (2.37). The models as developed contain the flexibility to handle unsteady response to

time varying incident wave conditions; however, we will be concerned exclusively with representing the response to a constant wave climate. In this guise, the models represent iterative schemes to determine the response to a steady state exciting force, and updated unknowns may be regarded as iterated values rather than advanced-in-time values.

Listings of the computer programs for the linear and nonlinear models are given in Appendix I together with some notes on running the programs.

## 2. THE GRID SCHEME AND LOCATION OF THE UNKNOWN QUANTITIES

The first step in constructing a finite difference model lies in choosing a network of discrete grids overlaying the physical domain of interest. The grid used by the present models is that of Noda <u>et al</u>. (1974), as illustrated in Figure 3-1. The physical domain is divided into regular grids of longshore extent  $\Delta y$  and offshore extent  $\Delta x$ . The topography is assumed to be periodic in the longshore y direction with a length  $\lambda$  given by

$$\lambda = (N - 1) \cdot \Delta v$$

Various requirements affecting the choice of grid are:

- 1. The grid must extend offshore far enough to remove the offshore region of the domain from the influence of currents driven by the surf zone, and to allow for the specification of a uniform longshore depth which will not significantly alter the wave refraction results in the nearshore.
- The grid mesh must be fine enough to resolve the surf zone in a reasonable manner.

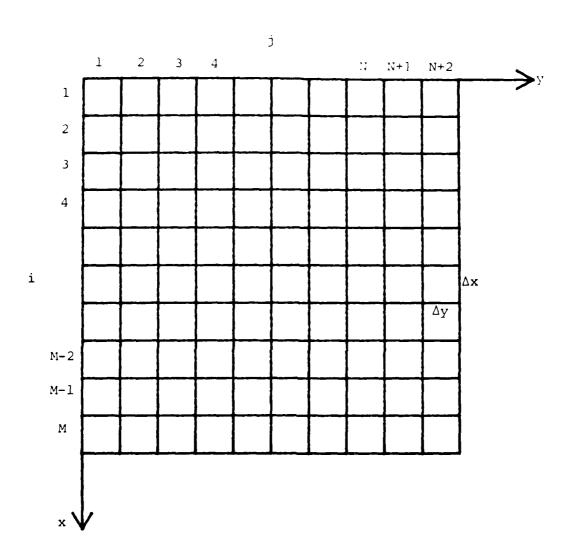


Figure 3-1. Grid Scheme [After Noda  $\underline{et}$ .  $\underline{al}$ . (1974)]

3. In the event that a single physical feature isolated in the longshore direction is to be modelled, the longshore extent of the grid must be sufficiently large to isolate the physical system from the effect of images created by the longshore periodicity requirement.

In the event that large, non-periodic physical features creating significant current patterns seaward of the breaker line are present, requirements (1) and (3) lead to the choice of a large grid, whereas requirement (2) can lead to choice of quite small offshore grid spacings on steep beaches. The resulting grid will often contain a large number of elements, leading to the requirement of large amounts of computer time to solve the complex set of governing equations.

The fixed and variable quantities are defined in relation to the grid structure as shown in Figure 3-2. The quantity  $A_{i,j}$  is defined at the grid center and represents any of the set of quantities

$$A_{i,j} = \{H, \theta, k, \overline{\eta}, S, D, \tau_b, \tau_s\}_{i,j}$$
 (3.1)

Velocities U and V are given at grid sides. This formulation relates naturally to the conservation law scheme of relating changes of a quantity in a bounded region to the fluxes of that quantity across the bounding surface, and is therefore physically correct in an heuristic sense, as well as possessing whatever degree of numerical accuracy consistent with the chosen difference schemes.

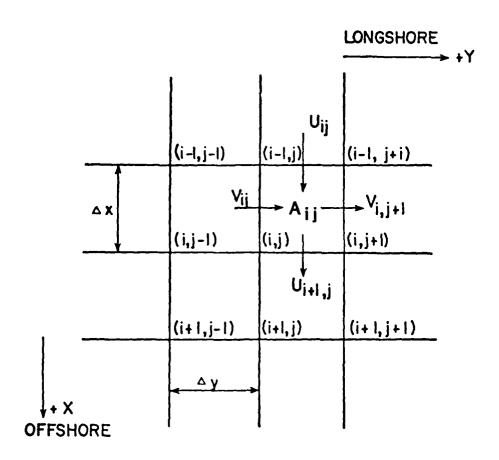


Figure 3-2. Velocity Components for Grid Block (i,j). All Other Variables (D,  $S_{xx}$ ,  $S_{xy}$ , H, etc.) Are Determined at Grid Center.

#### 3. BOUNDARY CONDITIONS

In order to formulate the numerical models, a scheme was established which incorporated the lateral periodicity requirements mentioned above and the no-flow requirements at the shore and the offshore grid row, as mentioned in Chapter II.

The user defined depth grid is established for the M by N portion of the total grid shown in Figure 3.1, with the requirement that

$$D_{i,N} = D_{i,1} \tag{3.2}$$

to satisfy the periodicity requirement. The grid N then extended to the  $N\,+\,1$  and the  $N\,+\,2$  columns according to

$$D_{i,N+1} = D_{i,2}$$

$$D_{i,N+2} = D_{i,3} {.} {(3.3)}$$

Similar periodicity requirements are met by all calculated quantities (the  $A_{ij}$  in Eq. (3.1)). The models calculate values of the  $A_{ij}$  quantities from the j = 2 row to the j = N row. Periodicity is then established by setting

$$A_{i,1} = A_{i,N}$$

$$A_{i,N+1} = A_{i,2}$$

$$A_{i,N+2} = A_{i,3}$$
(3.4)

The velocities  ${\tt U}$  and  ${\tt V}$  are treated somewhat differently in that the calculations

are performed from the j = 3 to the j = N+1 grid rows, with periodicity established accordingly.

At the offshore grid row (i = M), a no-flow condition is applied for U and V. This condition serves to bound the calculated velocities during initial start-up of the model; however, the condition is artificial in that the offshore side of the modelled area becomes a solid vertical boundary. This treatment leads to potential seiching in the model. The presence of a seiching mode in the model calculations has been discussed thoroughly by Birkemeier and Dalrymple (1971) and Ebersole and Dalrymple (1979), who have shown that the period of seiching can be accurately predicted by the shallow water formulas for known topographies. For example, for a basin of triangular cross-section, Wilson (1966) predicts the period of the first mode oscillation by

$$T = \frac{3.28L}{\sqrt{gh_{max}}}$$
 (3.5)

where

T = period of oscillation in the basin

L = length of the basin =  $(M - 1) \cdot \Delta x$ 

may = maximum still water depth in the basin.

Similarly, a no flow condition for the shore-normal velocity U is applied at the onshore grid row, whose position remains fixed during a model run. The linear model originally described by Birkemeier and Dalrymple (1976) included a provision for flooding shoreward dry grids in order to model the effect of wave set-up; model results have been seen to be somewhat insensitive to the correction provided by this provision. Flooding is not included in the nonlinear model of Ebersole and Dalrymple or in the present version of the linear model.

In addition to the lateral boundary conditions, the system of hyperbolic equations requires initial conditions for a complete solution. The models are started from a state of rest with no wave field present. In order to reduce the effect of seiching, the wave height H at the offshore grid is brought up to its full value gradually according to

$$H = H_0 \tanh \left(\frac{2t}{T}\right) , \qquad (3.6)$$

where

t = model time

T = arbitrary fixed time period.

Wave height is typically allowed to build up for 400 model iterations. It is also noted that, in principal, the seiching effect could be removed by setting  $\bar{\eta}$  to zero at the offshore boundary, rather than U.

#### 4. FINITE DIFFERENCE OPERATORS AND NOTATIONS

The derivations of the numerical models given by Birkemeier and Dalrymple (1976) and Ebersole and Dalrymple (1979) differ significantly in notation. For this reason, a standardized notation is presented here. We retain as far as possible the terminology of Ebersole and Dalrymple (1979) in describing both the linear and nonlinear models.

The numerical formulations require both averaging and differencing operations. Let F(x,y,t) be an arbitrary function varying in space and time. The average of the function over one grid spacing is given by

$$\overline{F(x,y,t)}^{x} = \frac{1}{2} \{F(x + \frac{\Delta x}{2}, y,t) + F(x - \frac{\Delta x}{2}, y,t)\}$$
 (3.7)

for an average in the x-direction. Successive averaging is given by

$$\overline{F(x,y,t)} \stackrel{xy}{=} \overline{F(x,y,t)} \stackrel{x}{=} y$$
 (3.8)

First derivatives can be given in terms of forward and backward differences over a single grid space, or as central differences over two grid spaces. We define the forward and backward difference operators, respectively, as

$$\delta_{\mathbf{x}}\{F(x,y,t)\} = \frac{1}{\Delta x} \{F(x + \Delta x,y,t) - F(x,y,t)\}$$
 (3.9)

$$\delta_{\overline{X}}\{F(x,y,t)\} = \frac{1}{\Delta x} \{F(x,y,t) - F(x - \Delta x,y,t)\}$$
 (3.10)

and the central difference operator as

$$s_{\hat{\mathbf{x}}}\{F(x,y,t)\} = \frac{1}{2\Delta x} \{F(x + \Delta x,y,t) - F(x - \Delta x,y,t)\}$$
 (3.11)

We also define an auxilary operator which represents the central difference at a grid center based on values at the grid sides

$$\delta_{\mathbf{x}}\{\mathbf{F}(\mathbf{x},\mathbf{y},\mathbf{t})\} = \frac{1}{\Delta \mathbf{x}} \quad \mathbf{F}(\mathbf{x} + \frac{\Delta \mathbf{x}}{2},\mathbf{y},\mathbf{t}) - \mathbf{F}(\mathbf{x} - \frac{\Delta \mathbf{x}}{2},\mathbf{y},\mathbf{t})\}$$
(3.12)

It is easily shown by direct substitution that the  $\delta_{\widetilde{X}}$  operator is related to  $\delta_{\widehat{Y}}$  through the relation

$$\delta_{\widehat{\mathbf{x}}}\{\overline{\mathbf{F}(\mathbf{x},\mathbf{y},\mathbf{t})}^{\mathbf{X}}\} = \delta_{\widehat{\mathbf{x}}}\{\mathbf{F}(\mathbf{x},\mathbf{y},\mathbf{t})\}$$
(3.13)

The nonlinear model makes extensive use of the  $\delta_{\tilde{X}}$  operator, while the linear model is formulated more conventionally in terms of the standard forward and backward differences given by Eqs. (3.9) and (3.10).

## 5. FINITE DIFFERENCE FORMS OF THE GOVERNING EQUATIONS - LINEAR MODEL

Before applying the finite difference scheme to the linear formulation, we rewrite the equations here for clarity. The equations of continuity and

x- and y-momentum are given respectively by

$$\frac{3\overline{n}}{3t} = -\frac{3}{3x} \text{ (UD) } -\frac{3}{3y} \text{ (VD)}$$
 (3.14)

$$\frac{\partial \mathbf{U}}{\partial \mathbf{t}} = -\mathbf{g} \frac{\partial \overline{\eta}}{\partial \mathbf{x}} - \frac{1}{\rho \mathbf{D}} \left\{ \frac{\partial \mathbf{S}_{\mathbf{x}\mathbf{x}}}{\partial \mathbf{x}} + \frac{\partial \mathbf{S}_{\mathbf{x}\mathbf{y}}}{\partial \mathbf{y}} - \frac{\overline{\tau}_{\mathbf{s}\mathbf{x}}}{\tau_{\mathbf{s}\mathbf{x}}} + \frac{\overline{\tau}_{\mathbf{b}\mathbf{x}}}{\tau_{\mathbf{b}\mathbf{x}}} \right\}$$
(3.15)

$$\frac{\partial \mathbf{V}}{\partial \mathbf{t}} = -\mathbf{g} \frac{\partial \overline{\mathbf{n}}}{\partial \mathbf{y}} - \frac{1}{\partial \mathbf{D}} \left\{ \frac{\partial \mathbf{S}_{\mathbf{x}\mathbf{y}}}{\partial \mathbf{x}} + \frac{\partial \mathbf{S}_{\mathbf{y}\mathbf{y}}}{\partial \mathbf{y}} - \overline{\tau_{\mathbf{s}\mathbf{y}}} + \overline{\tau_{\mathbf{b}\mathbf{y}}} \right\}$$
(3.16)

In deriving this set of equations, we have tacitly assumed that variations of  $\frac{1}{1}$  with respect to time are small in comparison to variations in U and V. As we are striving for a steady state solution, the model results should not be sensitive to this assumption. Care should be taken, however, in removing time derivatives of D in cases where time dependent results are desired.

In keeping with standard techniques for treating first order linear hyperbolic equations, difference equations are formulated using a forward time-forward space (FTFS) scheme for the continuity equation (3.14), and forward time-backward space (FTBS) formulation for the momentum equations (3.15) and (3.16). Recalling that depths and set-up are known at grid centers, while velocities are given at grid boundaries, equations (3.14) - (3.16) are written in finite difference form as:

$$\delta_{\mathbf{t}}\{\overline{\eta}\} = -\delta_{\mathbf{x}}\{\overline{U}\overline{D}^{\mathbf{x}}\} - \delta_{\mathbf{y}}\{\overline{V}\overline{D}^{\mathbf{y}}\}$$

$$\delta_{\mathbf{t}}\{U\} = -g \delta_{\overline{\mathbf{x}}}\{\eta\} - \frac{1}{\rho \overline{D}^{\mathbf{x}}} \left\{\delta_{\overline{\mathbf{x}}}\{S_{\mathbf{x}\mathbf{x}}\} + \delta_{\widehat{\mathbf{y}}}\{\overline{S_{\mathbf{x}\mathbf{y}}}\}^{\mathbf{x}} - \frac{1}{\sigma_{\mathbf{x}}} \frac{\mathbf{x}}{\sigma_{\mathbf{x}}} + \frac{1}{\sigma_{\mathbf{x}}} \frac{\mathbf{x}}{\sigma_{\mathbf{x}}} \right\}$$

$$(3.17)$$

$$\frac{\delta}{t}\{V\} = -g\delta \frac{1}{y}\{\overline{\eta}\} - \frac{1}{\rho \overline{D}} \frac{1}{y} \left\{\delta_{\widehat{\mathbf{x}}}\{\overline{\mathbf{S}_{\mathbf{x}y}}\} \right\} + \delta_{\overline{y}}\{\mathbf{S}_{yy}\} - \overline{\tau_{\mathbf{s}y}} + \overline{\tau_{\mathbf{b}y}} \right\}$$
(3.19)

Note that  $\delta_t(F)$  yields the forward difference

$$\delta_{t}(F) = \frac{F^{k+1} - F^{k}}{\Delta t} \tag{3.20}$$

where k and k+1 are successive time levels. Expanded forms of the equations (3.17) - (3.19) can be found in Birkemeier and Dalrymple (1976). At each iteration, the values of U and V are updated to time level k+1 using  $\overline{\eta}$  and forcing terms evaluated at time level k. Then  $\overline{\eta}$  is updated using the newly evaluated values of U and V at time level k+1. The method thus requires only one time level of storage for each of the unknown quantities.

Difference forms of the type used here have been discussed extensively by a number of authors (see, for example, Roache (1976)). The explicit method is subject to certain stability conditions. The problem of obtaining stability criteria for equations with non-constant coefficients is in general unsolved to date; however, we can make a reasonable guess based on constant-coefficient forms of the governing equations. If we drop the forcing terms, assume  $D \stackrel{>}{\sim} h$ , and hold h constant, we obtain

$$\frac{\partial \overline{\eta}}{\partial t} = -h \left\{ \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} \right\}$$

$$\frac{\partial U}{\partial t} = -g \frac{\partial \overline{\eta}}{\partial x}$$

$$\frac{\partial V}{\partial t} = -g \frac{\partial \overline{\eta}}{\partial y}$$
(3.21)

Cross-differentiating to eliminate U and V, we obtain the second-order hyperbolic equation for  $\overline{\eta}$ :

$$\frac{3^2 \tau_1}{4 t^2} = gh \left\{ \frac{3^2 \tau_1}{9 x^2} + \frac{3^2 \tau_1}{9 y^2} \right\}$$
 (3.22)

The stability criterion corresponding to this reduced equation is given by the Courant condition:

$$\Delta t = \frac{\Delta x}{\sqrt{2gh}} , \qquad (3.23)$$

assuming that  $\Delta y = \Delta x$ . Generalizing to the full model, the stability criterion (3.23) can be extended to include the effect of rectangular grids and the advection of disturbances by the mean currents.

$$\Delta t = \frac{\sqrt{(\Delta x)^2 + (\Delta y)^2}}{\sqrt{2gh} + |\vec{v}|}$$
 (3.24)

The stability criterion basically states that time steps in the model may not be so large as to allow long wave disturbances to pass completely through a grid in one iteration. Violation of the criterion leads to rapidly growing instability of the numerical solution. In practice, time steps on the order of 0.25 times the maximum  $\Delta t$  are used.

#### FINITE DIFFERENCE FORMS OF THE GOVERNING EQUATIONS - NONLINEAR MODEL

The set of nonlinear momentum equations (2.12) - (2.13), together with the continuity equation (2.11), require a more careful development in difference form than the previously described linear model. Nonlinear formulations are in a practical sense subject to a number of instability mechanisms which are

not strictly related to stability criteria for the corresponding linear formulations, as discussed by Roache (1976).

The nonlinear model has been formulated using a method which has been applied successfully to geophysical and tidal models by Lilly (1965) and Blumberg (1977). Using the difference and average operators defined in section 4, the equations (2.11-13) are rewritten as

Continuity:

$$\delta_{\hat{\mathbf{t}}}(\overline{\mathbf{n}}^{\mathbf{t}}) + \delta_{\widetilde{\mathbf{x}}}(\overline{\mathbf{D}}^{\mathbf{x}}\mathbf{u}) + \delta_{\widetilde{\mathbf{y}}}(\overline{\mathbf{D}}^{\mathbf{y}}\mathbf{v}) = 0$$
 (3.25)

X-Momentum

$$\delta_{\tilde{\mathbf{t}}} \{ \overline{D}^{X} \mathbf{U}^{-1} \} + \delta_{\tilde{\mathbf{x}}} \{ \overline{D}^{X} \mathbf{U}^{-1} \mathbf{U}^{-1} \mathbf{U}^{-1} \mathbf{V} \} + \delta_{\tilde{\mathbf{y}}} \{ \overline{D}^{-1} \mathbf{V}^{-1} \mathbf{U}^{-1} \mathbf{V} \} =$$

$$= -g \overline{D}^{X} \delta_{X} \{ \overline{\eta} \} + \frac{1}{\rho} \{ \overline{\tau}_{SX}^{X} - \overline{\tau}_{DX}^{X} - \delta_{\tilde{\mathbf{y}}} \{ \overline{s}_{XY}^{X} \mathbf{V} \} - \delta_{\tilde{\mathbf{y}}} \{ \overline{s}_{XY}^{X} \} \} + \overline{D}^{X} \delta_{\tilde{\mathbf{y}}} \{ \varepsilon_{Y} \delta_{\tilde{\mathbf{y}}} \{ \mathbf{U} \} + \overline{\varepsilon}_{X}^{X} \mathbf{V} \delta_{\tilde{\mathbf{x}}} \{ \mathbf{V} \} \}$$

$$(3.26)$$

Y-Momentum

$$\delta_{\widetilde{\mathbf{t}}} \{ \overline{\overline{\mathbf{D}}} \overset{\mathbf{v}}{\mathbf{V}} \overset{\mathbf{t}}{\mathbf{V}} \} + \delta_{\widetilde{\mathbf{x}}} \{ \overline{\overline{\mathbf{D}}} \overset{\mathbf{v}}{\mathbf{U}} \overset{\mathbf{y}}{\mathbf{V}} \overset{\mathbf{y}}{\mathbf{V}} ) + \delta_{\widetilde{\mathbf{y}}} \{ \overline{\overline{\mathbf{D}}} \overset{\mathbf{y}}{\mathbf{V}} \overset{\mathbf{y}}{\mathbf{V}} \overset{\mathbf{y}}{\mathbf{V}} ) \} =$$

$$- g \overline{\mathbf{D}} \overset{\mathbf{y}}{\mathbf{V}} \delta_{\mathbf{y}} \{ \overline{\mathbf{\eta}} \} + \frac{1}{\rho} \{ \overline{\tau_{\mathbf{s}\mathbf{y}}} \overset{\mathbf{y}}{\mathbf{V}} - \overline{\tau_{\mathbf{b}\mathbf{y}}} \overset{\mathbf{y}}{\mathbf{V}} - \delta_{\widetilde{\mathbf{y}}} \{ \mathbf{S}_{\mathbf{y}\mathbf{y}} \}$$

$$- \delta_{\widetilde{\mathbf{x}}} \{ \overline{\mathbf{S}_{\mathbf{x}\mathbf{y}}} \overset{\mathbf{x}\mathbf{y}}{\mathbf{V}} \} \Big\} + \overline{\mathbf{D}} \overset{\mathbf{y}}{\mathbf{V}} \delta_{\widetilde{\mathbf{x}}} \{ \varepsilon_{\mathbf{y}} \delta_{\widetilde{\mathbf{y}}} \{ \mathbf{U} \} + \overline{\varepsilon_{\mathbf{x}}} \overset{\mathbf{x}\mathbf{y}}{\mathbf{v}} \delta_{\widetilde{\mathbf{x}}} \{ \mathbf{V} \} \}$$

$$(3.27)$$

The formula for lateral mixing given by Eq. (2.46) has been substituted into Eqs. (3.26-27). Note that, following Eq. (3.13), the central difference on the time averaged wate set-up in Eq. (3.25) leads to

$$\frac{-t}{\delta_{t}(\eta)} = \delta_{t}(\eta) = \frac{-k+1}{\eta_{1,j}^{1} - \eta_{1,j}^{k-1}}$$
(3.28)

The governing equations in this case then contain function values at three times levels, given by k+1, k, and k-1. The equations (3.25-27) can be found written out with respect to the i,j grid in Ebersole and Dalrymple (1979). These three equations can also be written in the following abbreviated form,

$$\frac{-k+1}{\eta_{i,j}} = \frac{-k-1}{\eta_{i,j}} + 20t F_1$$
 (3.29)

$$\mathbf{U}_{i,j}^{k+1} = \mathbf{A} \ \mathbf{U}_{i,j}^{k-1} + 2nt \ \mathbf{F}_{2}$$
 (3.30)

$$v_{i,j}^{k+1} = B v_{i,j}^{k-1} + 2it F_3$$
 (3.31)

where A and B are functions of the depth alone and  $F_1$ ,  $F_2$ , and  $F_3$  are functions of all the variables in the problem. The quantities  $F_1$ ,  $F_2$ , and  $F_3$  contain quantities evaluated at time level k and k-1.

The method of solution for Eqs. (3.29-31) is based on a leapfrog scheme, and thus requires the storage of three time levels of values for all the calculated variables. In order to select the model, a single step is taken based on a forward difference formulation similar to that described in conjunction with the linear model. The forward difference formulation can be indicated schematically by

$$\vec{\eta}_{i,i}^{k+1} = \vec{\eta}_{i,j}^{k} + \Delta t F_{1}$$
(3.32)

$$\mathbf{U}_{i,j}^{k+1} = \mathbf{C} \ \mathbf{U}_{i,j}^{k} + \Delta \mathbf{t} \ \mathbf{F}_{4}$$
 (3.33)

$$v_{i,j}^{k+1} = D v_{i,j}^{k} + \Delta t F_{5}$$
 (3.34)

The computational method is schematized in Figure 3-3.

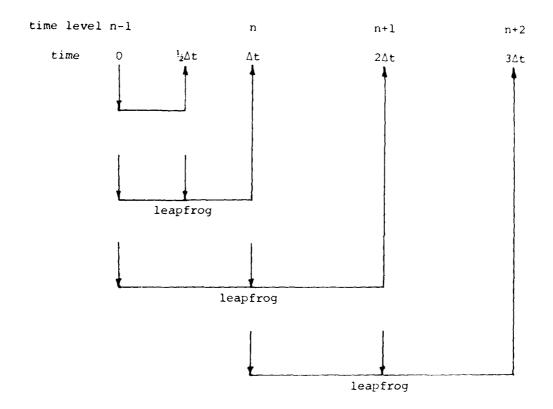


Figure 3-3. General Leapfrog Solution Scheme

The stability criterion for the present scheme was assumed to be given by Eq. (3.24), which has physical if not mathematical significance in the present situation. In practice, as is the case of the linear model, it was necessary to reduce the maximum allowable time step to a value significantly below the one predicted by the stability criterion.

The nonlinear model was also subject to a second computational stability problem. In general, computational schemes for first order equations which are

centered in space and time (CSCT) exhibit forms of unstable behavior. In particular, in the context of the first order parabolic diffusion equation, such explicit CSCT schemes can be shown to be unconditionally unstable. In the present case, as the model approached a steady state, the solution diverged into two disjoint solutions; one associated with the even time steps and the other the odd steps. These solutions oscillated with growing amplitudes about the steady state solution. In Roache (1976), the author referred to this as time splitting.

To alleviate the problem, a leapfrog-backward correction scheme, Kurihara (1965), was initiated every tenth time step. The scheme is shown below as,

$$h^* = h^{k-1} + 2\Delta t G^k$$
 (3.35)

$$h^{k+1} = h^k + \Delta t G^*$$
 (3.36)

where h may be U, V or  $\overline{\eta}$ . Equation (3.35) is simply the leapfrog calculation done by the Eqs. (3.29-31) where \* denotes the new or "interim" time level. Using the new values U, V,  $\overline{\eta}$  at time \*, the functions G\*, like the functions  $F_1$ ,  $F_2$ , and  $F_3$  from Eqs. (3.29-31) are calculated and used in Eq. (3.36) which is merely a backwards difference in time to the level k.

This scheme was chosen because it damps the computational mode of the solution while leaving the physical mode relatively unaffected. For a more in-depth discussion the reader is referred to the work by Kurihara. With this correction scheme included, which essentially "ties" the solutions together every tenth iteration, the model proceeded to reach a steady state without any further time-splitting instability.

#### THE NUMERICAL SCHEME FOR REFRACTION AND THE WAVE HEIGHT FIELD

The equations governing wave refraction, wave height, and wave number are given by Eqs. (2.35), (2,37), and (2.36) respectively. The method of solving these equations for the unknown  $\theta_{i,j}$ ,  $H_{i,j}$  and  $k_{i,j}$  is identical in both the linear and nonlinear models. The method was given originally by Noda et al. (1974).

If Eq. (2.36) is differentiated with respect to x to get  $\frac{\partial k}{\partial x}$  and with respect to y to get  $\frac{\partial k}{\partial y}$ , these quantities can be substituted into Eq. (2.35), which can then be written in the following form:

$$A \frac{\partial \theta}{\partial x} = B \frac{\partial \theta}{\partial y} = C \tag{3.37}$$

where A, B and C are functions of the quantities  $\sin \theta$ ,  $\cos \theta$ , k, h, u and v. By taking a forward difference in x to approximate  $\frac{\partial \theta}{\partial x}$  and a backwards difference in y to approximate  $\frac{\partial \theta}{\partial v}$ , Eq. (3.37) becomes:

$$\theta_{i,j} = D + E \theta_{i,j-1} - F \theta_{i+1,j}$$
 (3.38)

where D, E and F are now functions of the quantities  $\sin \theta_{i,j}$ ,  $\cos \theta_{i,j}$ ,  $k_{i,j}$ ,  $h_{i,j}$ ,  $u_{i,j}$ ,  $v_{i,j}$ . To evaluate  $\sin \theta_{i,j}$  and  $\cos \theta_{i,j}$  Noda used a first order Taylor series expansion to the four neighboring grids (i+1,j), (i-1,j), (i,j+1) and (i,j-1), summed the results and took an average value.

The theta field  $\theta_{i,j}$  is solved for in the following way. Snell's Law is used to approximate the angles at the offshore row. Working shoreward Eq. (3.38) is solved for in a row-by-row relaxation until the angles converge to their correct values with wave-current interaction included. After each updated value of theta, a new wave number must be solved for.

Eq. (2.36) can be written as

$$E(k) = \left\{ gk \tanh(kh) \right\}^{1/2} + uk\cos\theta + vk\sin\theta - \frac{2\pi}{T} = 0 . \qquad (3.39)$$

To solve for the wave number, k, after each updated angle is found, the Newton-Raphson Method, or "method of tangents", is used. This method states that

$$k_{\text{new}} = k_{\text{old}} - \frac{E(k_{\text{old}})}{E'(k_{\text{old}})}$$

Differentiating Eq. (3.39),  $k_{\text{new}}$  is iteratively solved for until  $|k_{\text{new}} - k_{\text{old}}| \le .001 |k_{\text{new}}|$ .

The wave height field is calculated in much the same way as the wave angle field. Multiplying Eq. (2.37) by  $\frac{H}{2}$  and letting  $\frac{\partial H}{\partial t} = 0$ , the energy equation can now be written in the form

$$A \frac{\partial H}{\partial x} + B \frac{\partial H}{\partial y} = C H$$
 (3.40)

where A, B and C are functions of u, v cos  $\theta$ , sin  $\theta$ , C<sub>g</sub>,  $\Delta x$ ,  $\Delta y$  and the radiation stresses. Taking a forward difference in x to approximate  $\frac{\partial H}{\partial x}$  and a backward difference in y to approximate  $\frac{\partial H}{\partial y}$  and solving for H<sub>i,j</sub>, it can be shown that

$$H_{i,j} = D H_{i,j-1} - E H_{i+1,j}$$

where D and E are functions of the same quantities as A, B and C. Again the offshore row of wave heights are obtained from shoaling and refraction due to Snell's Law and the wave height field is determined by relaxing row by row in the shoreward direction. On each row a solution for the wave height is reached when  $|H_{new} - H_{old}| \le .01 H_{new}$ . After each updated value of  $H_{i,j}$ , a breaking wave height is also calculated from the breaking criteria given by the Miche

formula

$$\left(\frac{H}{L}\right)_b = .12 \tanh(kh)_b$$
.

If the calculated  $\mathbf{H}_{i,j}$  is larger than the allowable breaking height, the height  $\mathbf{H}_{i,j}$  was set equal to the breaking height.

#### CHAPTER IV

#### CALIBRATION OF THE NEARSHORE CIRCULATION MODELS

In order to make the circulation model more generally applicable to prediction of field conditions, both versions of the model were calibrated using field data. The calibrations consisted of determining a monochromatic deepwater wave condition and a uniform wind condition, and then running the models using the field conditions and measured bathymetry. Adjustable coefficients were then tuned to obtain the best possible qualitative and quantitative fit between the currents predicted by the model and those measured in the field.

In this chapter, the field data set used for calibration is described. Results for the circulation models are then shown for a range of coefficient values.

## 1. FIELD DATA USED FOR CALIBRATION

Field data used during calibration of the nearshore circulation models was obtained from the results of the Nearshore Sediment Transport Study (NSTS) experiment conducted at Torrey Pines beach, near La Jolla, Ca., (see Figure 4-1) in November - December 1978. The results of this study were chosen as being applicable to calibration of the models for several reasons. Torrey Pines beach is a long, straight beach with fairly uniform and parallel offshore contours. The field bathymetry was thus easily adapted into the model's scheme of longshore periodicity.

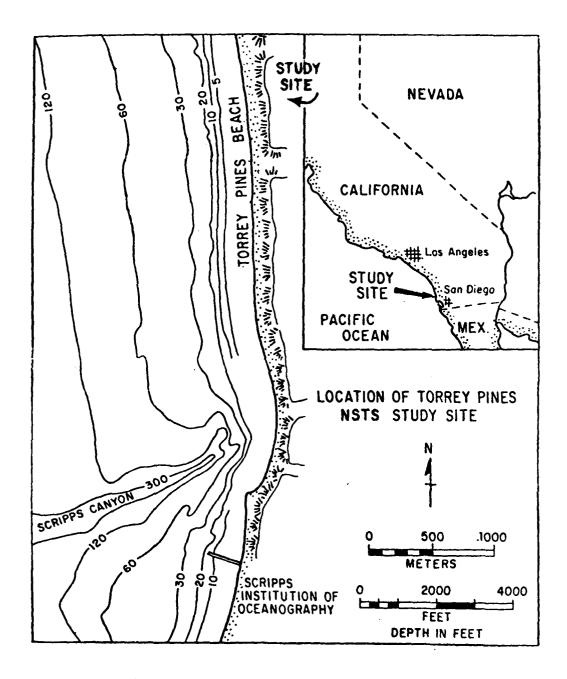


Figure 4-1. Location of NSTS Torrey Pines Experiment. (From Gable, 1979)

The experiment itself produced a detailed picture of nearshore currents and waves, with up to 22 current meters, 10 pressure gages, and 7 wave staffs being operated simultaneously. Thus the resolution needed to accurately fit the model predictions was present in the field data. Gable (1979) gives a detailed description of the site, instrumentation, and conduct of the NSTS experiment. The arrangement of fixed instruments used in the experiment is shown in Figure 4-2. Angles and distances used in this report will be with respect to the baseline (0 offshore distance) in Figure 4-2. Two separate bathymetry maps are shown in Figures 4-3 and 4-4. It is noted that the survey of Nov. 9, 1978 indicates the presence of a shallow channel oriented almost perpendicular to the baseline at about 40 m left of the main range (0 m alongshore). This feature is not present in the Nov. 18, 1978 survey, which, on the whole, exhibits greater random fluctuation in the location of the contours. Both the channel in the Nov. 9 bathymetry data and the unevenness in the Nov. 18 data appear to be transient features, as will be discussed below.

## 1.1 Choice of Field Data for Calibration

Several requirements were chosen in order to determine a valid set of field data for comparison to the numerical model. First, the numerical models in their basic state are designed to be run with a monochromatic deepwater wave condition. It was therefore required that the wave field for the chosen data be narrow banded both in a frequency and directional sense. The presence of a second wave component at a different direction than the primary component introduces a forcing mechanism

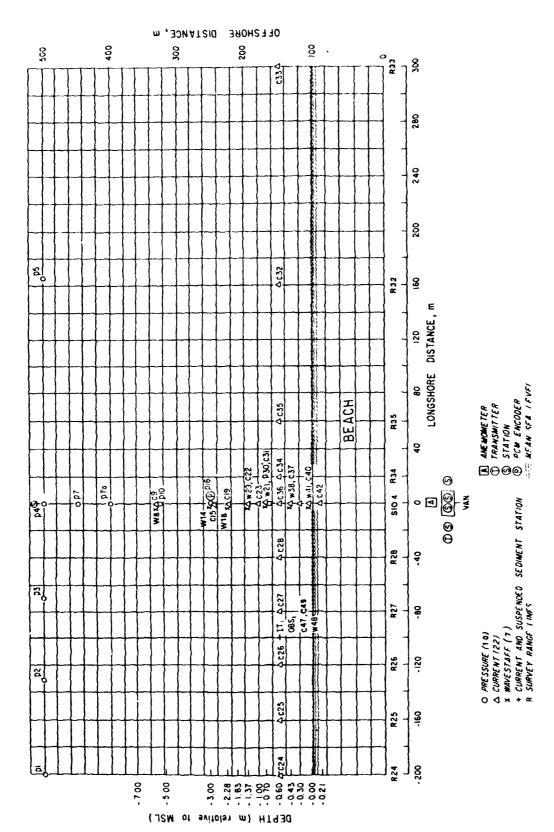
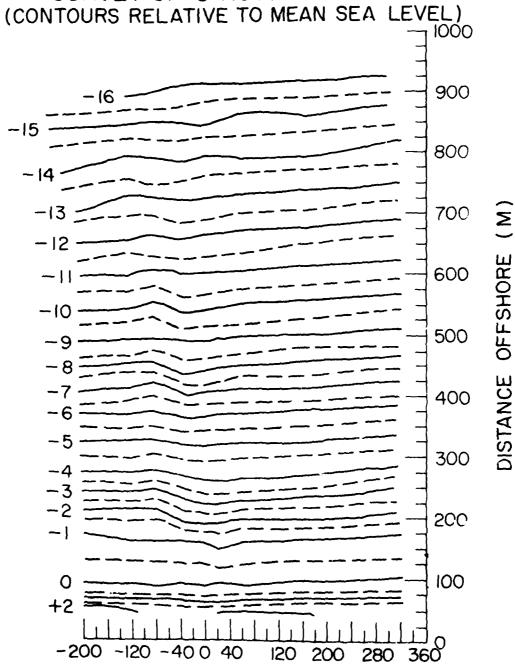


Figure 4-2. Instrumentation for NSTS Torrey Pines Experiment. (From Subl., 1979)

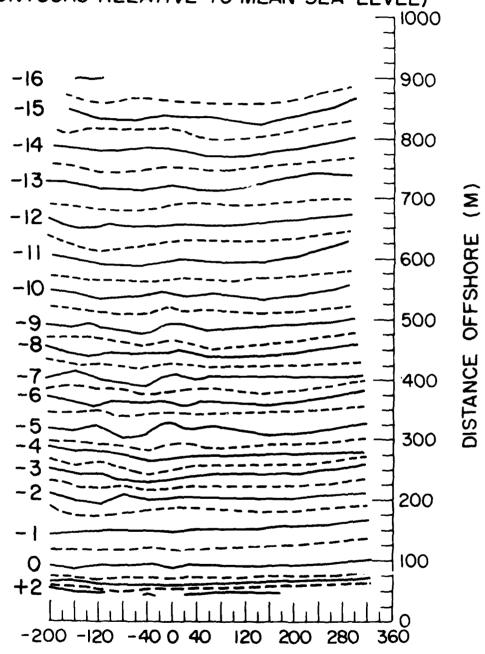
# NEARSHORE BATHYMETRY-TORREY PINES BEACH SURVEY OF 9 NOVEMBER 1978



LONGSHORE DISTANCE (M) RELATIVE TO MAIN RANGE

Figure 4-3. Nearshore Bathymetry, Nov. 9, 1978 (from Gable 1979)

## NEARSHORE BATHYMETRY-TORREY PINES BEACH SURVEY OF 18 NOVEMBER 1978 (CONTOURS RELATIVE TO MEAN SEA LEVEL)



LONGSHORE DISTANCE (M) RELATIVE TO MAIN RANGE

Figure 4-4. Nearshore Bathymetry, Nov. 18, 1978 (from Gable 1979)

which would tend to produce rip cells on a plane beach, as shown by Dalrymple (1975). Just such a case was treated by a simplified refraction model in Ebersole and Dalrymple (1979), but the capability to handle the condition has not been retained in the final model versions since the refraction scheme used does not model the interaction of different waves. In addition, the use of a 17 minute average of the field measured currents in order to obtain fairly steady conditions precluded the modelling of essentially transient circulation phenomenon.

Secondly, since it was desired to calculate a steady state wave and current field, it was required that wave and wind conditions be nearly steady over the interval of averaged field measurements. This required either a quiet or unidirectional wind field as well as fairly steady wave direction, height and period.

The field data set available from the NSTS results was roughly screened on the basis of the beach observations given in Gable (1979). In particular, observation of long crested waves indicated the presence of narrow banded directional spectra. It was found that the NSTS data presented a problem, in that almost all data sets exhibited at least some degree of bi-directionality, with waves approaching from both the north and south. The data chosen for initial calibration has a somewhat smaller wave component from the north than other records, but is still suspect as a valid calibration standard.

## Data Set Number 1

The NSTS data tapes divide the current and pressure records into 17 minute segments. The first data set chosen for use in cailbration,

and subsequently used for the majority of calibration runs, was taken from the second 17 minute segment of the test of Nov. 10, 1978. The 17 minute segments were further subdivided into four 4.25 minute segments, and averaged current fields were plotted for each 4.25 minute segment. Two representative plots for the first data set are shown in Figure 4-5a and b.

Based on an average of the 4.25 minute average velocity profiles, an average 17 minute velocity profile was constructed for data values on the main range (offshore array of meters) and is shown in Figure 4-6. The resulting velocity profile indicates a longshore current of about 8 cm/sec magnitude offshore of the surf zone. This current is too far outside the breaker line to be surf driven, and may be due to the presence of a tidal or seasonal current. The effect of this current on the model results is discussed below.

The monochromatic deepwater wave conditions determined for data set No. 1 were as follows:

Wave period T: 14.52 seconds

Wave height H : 0.62 meters

Wave angle A: 165.7° measured clockwise from +x

(offshore direction).

The uniform wind conditions were:

Wind speed W: 7.2 meters/second

Wind angle  $\alpha$ : 294.5° measured clockwise from -x

(onshore) direction.

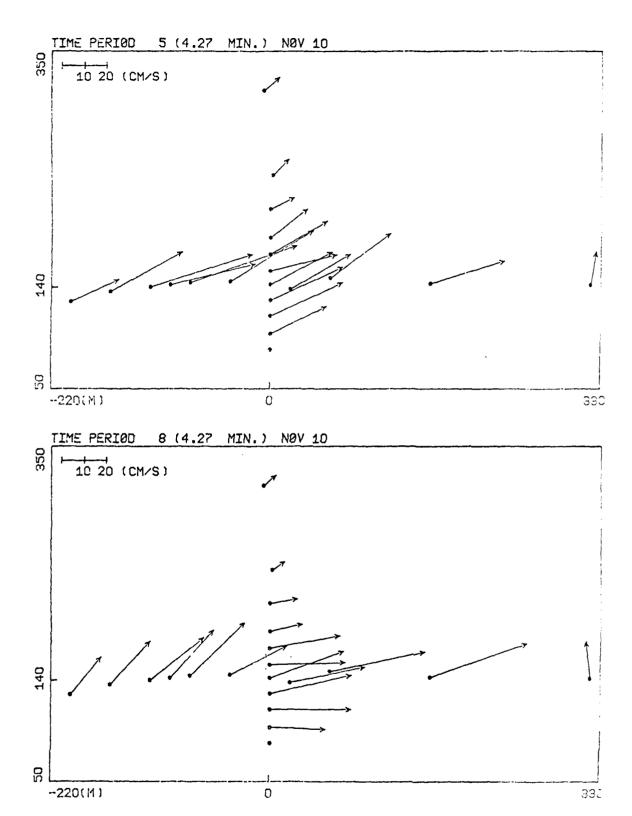


Figure 4-5. 4.27 Minute Average Current Vectors, Nov. 10, 1978.

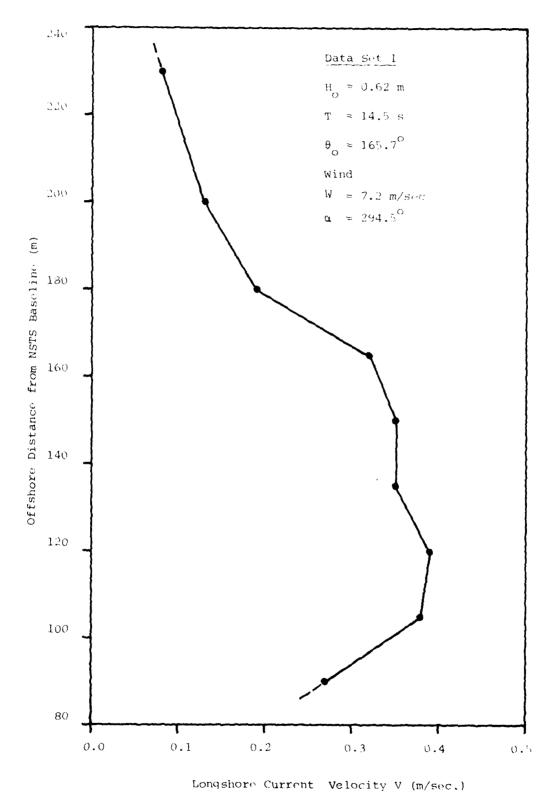


Figure 4.6 Average Field Velocity Profile Data Set 1.

## Data Set Number 2

Data Set Number 1 represented the only strongly unidirectional, narrow banded wave spectrum contained in the Torrey Pines data. The remaining data sets, even in the absence of locally generated short wind waves, exhibited at least a strong tendency towards bidirectionality, with spectral peaks nearly symmetrically placed about the shore-normal axis. Since it is anticipated that measured wave fields in general would seldom exhibit the narrow banded, unidirectionality required as input into the model, a data set was constructed based on averaging over the parameters of the measured wave field in order to test the response of the model using a "best guess" for the desired input parameters.

The data chosen for this test was from the eighth 17-minute time period of the November 15 data. Wave energy was contained in two directional peaks in a narrow frequency band (Figure 4-7). Using directional spectra supplied by Pawka (1980), the data set was constructed by summing the mean energy density over all frequencies in the dominant spectral peak. The wave angle was chosen as the average of the dominant angle at each frequency weighted by the energy densities. The peak energy containing frequency was taken as the dominant frequency. The resulting data set follows:

Wave Period T: 14.71 seconds

Wave Height  $H_0$ : 0.43 meters

Wave Angle A: 168° measured clockwise from +x

(offshore direction)

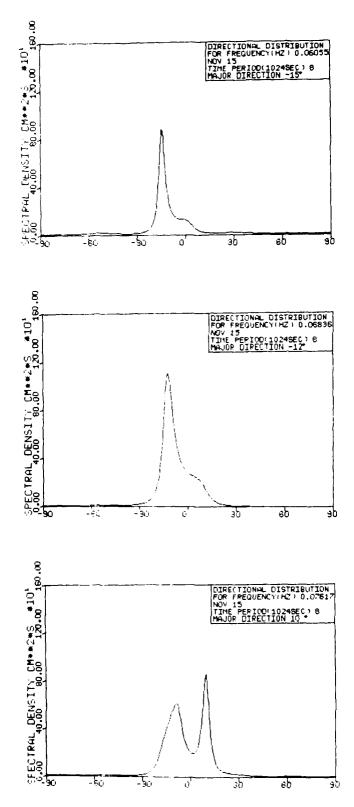


Figure 4-7. Directional Distribution of Wave Energy at Peak Frequencies, Nov. 15, 1978 (supplied by S. Pawka, 1980)

There was no significant steady wind component.

Wind speed W : 0.0 meters/second

Wind angle  $\alpha$ : not applicable.

The resulting data set has an indeterminant connection with the measured field data, and at best the model could be expected to exhibit results in qualitative agreement with the field data.

Figure 4-8 shows a plot of average longshore current over the 17 minute period of data collection. Individual plots (not shown) of 4.25 minute averages show a great deal of scatter in peak velocities and shape of the profile, indicating some unsteadiness in the current field, as would be expected due to the bi-directional wave field.

### 2. CALIBRATION OF THE MODELS

Both the linear and nonlinear models have a bottom friction factor f and the Van Dorn coefficients  $K_1$  and  $K_2$  as adjustable parameters. In addition, the nonlinear model has adjustable coefficients of lateral eddy mixing in both the longshore and offshore directions.

The Van Dorn wind stress formulation used in the models is intended to represent the transfer of momentum from a wind field to the water column, leading to a wind-induced longshore current for wind stress applied in the long shore direction, and wind set up for wind blowing towards shore. Wind set up cannot currently be accurately calibrated in the present models due to the artificial barrier at the offshore grid row; no additional water can

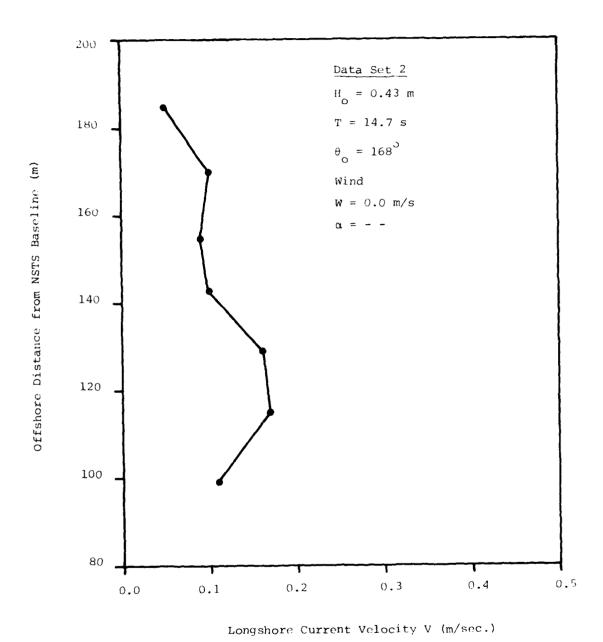


Figure 4-8 Average Field Velocity Profile Data Set 2

enter the model after the start of the run with a given depth grid. The parameters used in the Van Dorn formula have been tested in previous large scale models (Pearce, 1972), and have been found to be satisfactory.

With the elimination of the wind stress coefficients, only the bottom friction coefficient, f, remained to be calibrated in the linear model. The procedure used was to choose a value of f for both models based on a comparison of field data with the linear model. The value of f chosen was then used in the nonlinear model as a first approximation, and values of the eddy mixing coefficients were adjusted to again obtain a best fit between the results of the nonlinear model and the field data. It should be noted, however, that there is no a priori reason that both models should behave optimally with the same value of f.

## 2.1 Linear Model Calibration

Runs of the linear model were conducted using the deepwater wave conditions of Data Set 1 and the measured bathymetry of Nov. 9, 1978. For all values of f chosen, rip currents formed near the shallow channel seen in the Nov. 9 bathymetry. These rip currents were not apparent in the Nov. 10 currents (Figure 4-5), where they would affect the main range velocity profile. An example of the current field calculated using the Nov. 9 bathymetry is shown in Figure (4-9). The value of f for the run shown was 0.01.

It was tentatively concluded at this point that the shallow channel seen in the Nov. 9 data was a transient feature and was not present on Nov. 10, juding from the uniformity of the measured currents. It was decided to run a model using a bathymetry based on a longshore average of the Nov. 9 bathymetry

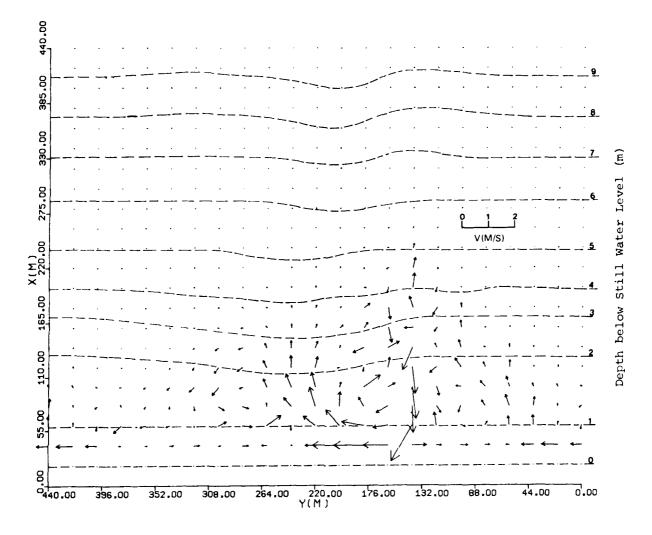


Figure 4-9 Currents Induced in Field Using Nov. 9 Bathymetry Nonlinear Model: Data Set 1.

data. The longshore extent of the beach was arbitrarily chosen as 200 meters. The profile is shown in Figure 4-10.

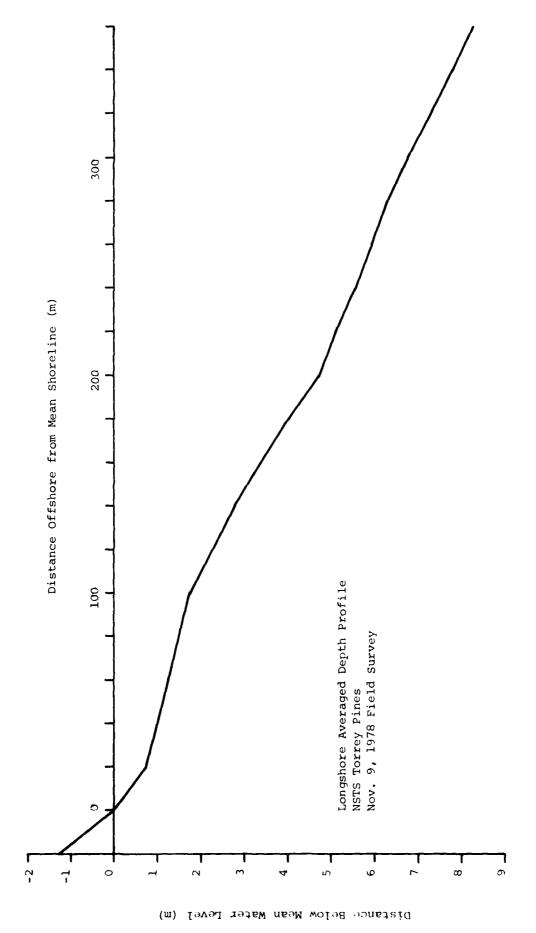
Using the longshore averaged bathymetry, model runs were conducted for a range of f values. Velocity profiles for values of f of 0.01, 0.015 and 0.02 are shown in Figure 4-11, in comparison to the current distribution measured in the field. In addition, a "corrected" field current distribution constructed by subtracting the 0.08 m/sec offshore current is shown as the dashed line.

Figure 4-11 shows that, by using a value of f equal to 0.015, the linear model closely predicts the maximum velocities and the general velocity distribution in the surf zone. The longshore current predicted by the model dies off more quickly offshore due to the absence of lateral mixing effects in the linear model.

# 2.2 Nonlinear Model Calibration

The nonlinear model was run using Data Set 1 and the value of  $f = 0.015 \text{ obtained from the linear model calibration.} \quad \text{Three sets of mixing}$  coefficients  $\epsilon_{_{\mathbf{X}}}$  (or N) and  $\epsilon_{_{\mathbf{V}}}$  were used (see Equation (2.40)).

<u>N</u>	$\frac{\varepsilon}{y}$	
0.000	0.00	no mixing
0.0025	0.25	
0.005	0.50	



Longshore Average Depth Profile, Torrey Fines, November 9, 1978. Figure 4-19

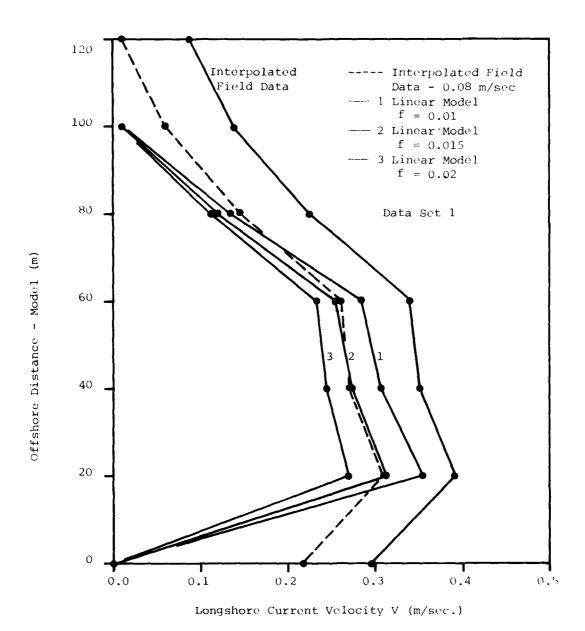


Figure 4-11 Variation of Longshore Current with Friction Factor in the Linear Model.

Results for f = 0.015 are shown in Figure 4-12. It was found that the inclusion of mixing satisfactorily extended the velocity profile in the offshore direction, but in both cases, including mixing, the current magnitudes in the surf zone were underpredicted. The model was therefore retested using a smaller value for the friction coefficient, f = 0.01. Results are shown in Figure 4-13. The smaller value of f is seen to correct for the underprediction of longshore current. Coefficient values for the nonlinear model were chosed based on the second set of results,

$$f \approx 0.01$$

$$N = 0.0025$$

$$\varepsilon_{\rm v} \approx 0.25$$

# 2.3 Response of Both Models Using Data Set 2

The linear and nonlinear models were run using Data Set 2 and the calibrated coefficients obtained above. Results for the linear model are shown in Figure 4-14. Nonlinear model results were similar to the linear model results. Both models were seen to overpredict the maximum longshore current in comparison to the averaged field data, and to underpredict the offshore extent of the longshore current. It is likely that a better fit to the field data could be obtained by artificially increasing the lateral mixing in the nonlinear model. However, the field data represents the average of a complex flow pattern, where the effect of mixing in the averaged data is induced by large scale phenomenon not likely to be found in the steady current fields induced by a unidirectional wave field. Since it is likely that the magnitude of artificial mixing would vary greatly as a function of

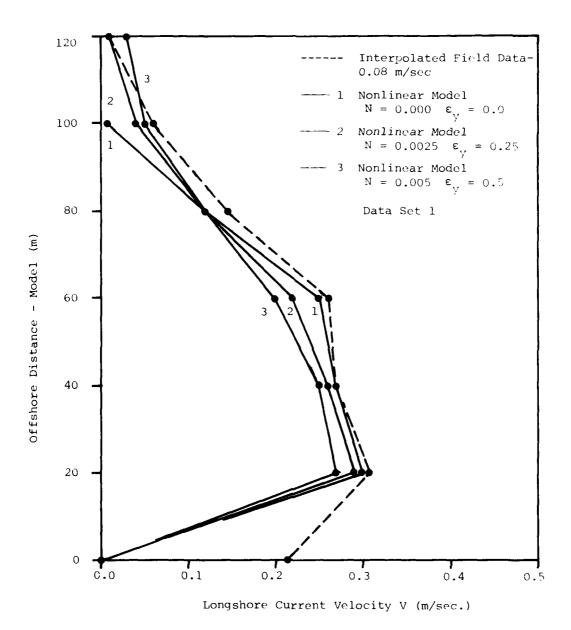


Figure 4-12 Variation of Longshore Current with Lateral Mixing in the Nonlinear Model. f = 0.015

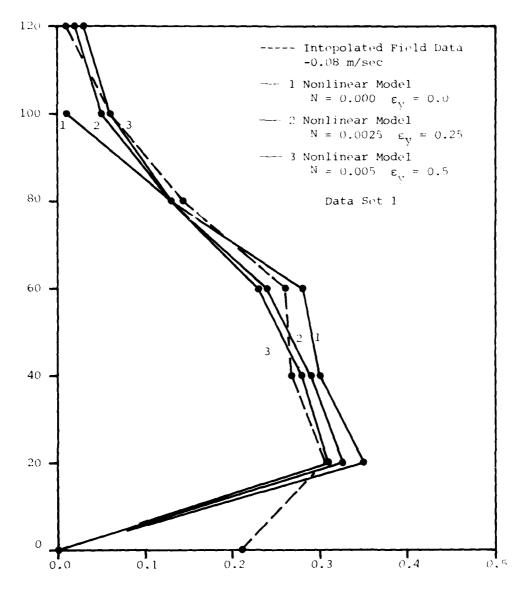


Figure 4-17 Variation of Longshore Current with Lateral Mixing in the Nonlinear Model. f = 0.010

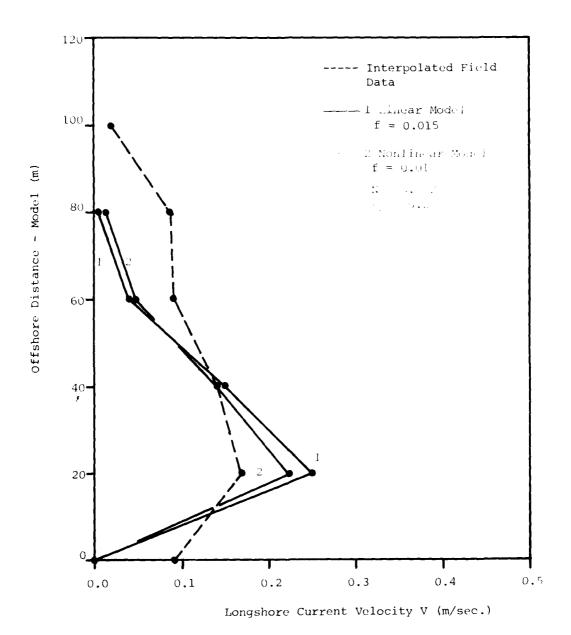


Figure 4-14 Longshore Current in the Linear and Nonlinear Models. Data Set 2

wave directionality and spatial complexity, it would be unjustified to alter the parameters of the model to fit a single case. It may become possible at some future date to estimate mixing parameters based on the characteristics of the random wave field.

A plot of the velocity vectors for data set 2 obtained using the calibrated model and the November 18 bathymetry is shown in Figure 4-15.

As in the November 10 case, the circulation pattern is seen to be sensitive to the bottom variations. This result is probably due to the low values obtained for the friction coefficient f.

#### DISCUSSION OF THE CALIBRATED COEFFICIENTS

The value of the friction factor f obtained in this study differs significantly from the value used in previous work and retained by Allender et al. (1981). Based on a bottom shear stress relation given by Eqs. (2.27-2.28), Birkemeier and Dalrymple (1976) chose a value of  $C_f = 0.01$ , which corresponds to a choice of f = 0.08. This value of f is carried over into the results discussed in the next chapter. However, model calibration has indicated that the value of f is more of the order 0.01-0.02, with values of 0.015 and 0.01 chosen for the linear and nonlinear models respectively. It is felt that this alteration in choice of the friction factor requires some discussion.

Many formulae exist to calculate the bottom friction factor under waves, the most successful being those of Jonsson (1966) and Kajiura (1968). Writing Kajiura's formula in a form given by Dalrymple and Lozano (1978), we obtain

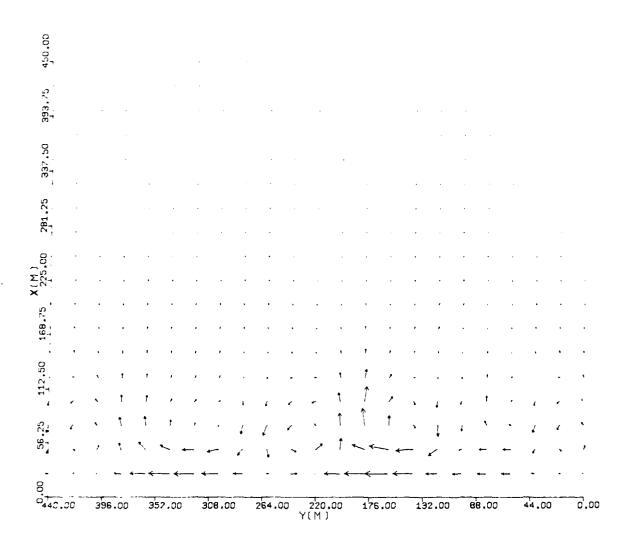


Figure 4-15. Currents Induced on Nov. 18, 1978 Bathymetry Using Data Set 2: Nonlinear Model.

$$C_f = \frac{f}{8} = 1.41 \left\{ \frac{4\pi d}{T(gh_b \kappa^2)^{1/2}} \right\}^{2/3}$$

where d is the median sand grain dimeter and  $\kappa$  is the breaking index. The value of f at the breaker line represents a reasonable choice for an average value over the surf zone region. For Torrey Pines Beach, d is approximately given by

$$d \sim d_{50} = 0.27 \text{ mm}$$

For the field data used,  $\boldsymbol{h}_{\boldsymbol{b}}$  is taken as approximately 1.5 m. This yields a value of

$$C_f = .0025 \text{ or } f = 0.02$$

The values of f obtained during calibration are thus of the correct order of magnitude for flows over a planar bed with no ripples. However, the real physical bottom being studied should exhibit a higher roughness, with length scales based on ripple geometry rather than the sand grain diameter, indicating that the initially chosen value of  $C_f = 0.01$  is probably more correct on physical grounds.

In this regard, we note the questionable practice of using distinctly bi-directional wave data to generate monochromatic input wave conditions for calibration purposes. The calibration obtained here possible constitutes a valid site specific calibration for the Torrey Pines beach, since it was found to be possible to predict net longshore flows resulting from wave fields with several components. In a practical sense, few data sets exist which are strictly useful for calibration purposes.

The values of the offshore mixing coefficient N chosen in this study are approximately one order of magnitude smaller than the corresponding value suggested by Bowen and Inman (1974), who investigated a group of dye dispersion studies performed by various investigators. Some indication that a larger value of N may be desirable is given by Figure (4-9): however, the validity of the field bathymetry is suspect in this case. It should be noted that the model exhibits a certain degree of numerical diffusion when large grid spacings are used, indicating that the value of N chosen should be less than the corresponding physically realistic value in any case.

## Chapter V

# EXAMPLES OF NUMERICAL RESULTS USING THE NEARSHORE CIRCULATION MODELS

## 1. INTRODUCTION

Various results of calculations using the linear and nonlinear models have been described in detail in Birkemeier and Dalrymple (1976) and Ebersole and Dalrymple (1979). Results pertaining to the questions of model stability and convergence have been mentioned in the previous chapters, with special attention to the seiching mode of oscillation generated at model start-up. In this chapter, results of model calculations in specific situations will be discussed, with emphasis on comparison to analytic models, and to bottom topographies which reproduce earlier efforts.

In addition to the general facilities for user-defined input, each of the models described in the two previous studies contained specialized facilities for the purpose of illustrating specific situations not covered by the basic model structures. These special cases are discussed here for completeness, although in most cases the final model versions may not retain the corresponding capability.

#### 2. SPECIFIC APPLICATIONS OF THE LINEAR AND NONLINEAR MODELS

In this section, we review results presented by Birkemeier and Dalrymple (1976) and Ebersole and Dalrymple (1979). In addition, we present results for an additional form of generalized topography.

# 2.1 Plane Beach Applications

Historically, the first application of the averaged momentum flux formulation presented in Chapter II to nearshore dynamics was made in an attempt to explain the phenomenon of wave set-up and longshore wave-induced currents in the surf zone. In the simplest formulation, the equation lead to a linear longshore current profile as shown in Figure 2-2 (Longuet-Higgins, 1970a). The addition of a turbulent stress term representing the effect of lateral mixing leads to a smoothed profile which is more representative of observed current distributions, as discussed by Longuet-Higgins (1970b). In the development in Chapter II, a lateral mixing model in the x and y directions was outlined based on the model used by Longuet-Higgins. Here, we review results calculated both with and without the lateral mixing effects.

Birkemeier and Dalrymple (1976) presented results for set-up resulting from normally incident waves on a plane slope, as shown in Figure 5-1 in comparison with the latoratory measurements of Bowen et al. (1968). Since, for this case, no currents are generated, the distinction between the linear and nonlinear models are inapplicable. The model is seen to accurately reproduce aspects of the solution based on linear incident waves, including the sharp drop in the mean water level just outside of the breaker line. It is noted that this drop can be eliminated, and a more realistic solution obtained, by the use of radiation stress terms derived from choidal wave theory (James 1974)). This possible refinement has not been included in the models.

Birkemeier and Dalrymple also investigated the dynamic set-up resulting from a time varying incident wave height given by

$$H_{o} = H_{s} + A \sin \left(2\pi n \frac{\Delta t}{T_{g}}\right)$$
 (5.1)

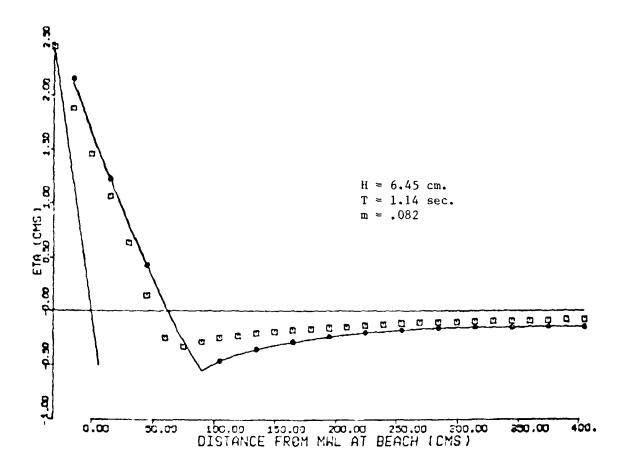


Figure 5-1. Set-up on a Plane Beach

☐ - Bowen et. al. (1968) experiment
. - Linear Model

where

 $H_{c} = starting wave height$ 

A = amplitude of variation

n = iteration index

 $T_g = group period.$ 

Results for dynamic set-up in comparison to incident wave height are shown in Figure 5-2. As an example of the seiching response of the model, a case was also run where the group period corresponded to the seiche period of the model as given by Eq. (3.5). Figure 5-3 indicates the resulting instability in the set-up which represents the growth of the seiche.

In the previous example, a model seiche appeared as a forced response to the applied wave-induced stress. Figure 5-4 indicates a more typical result of a seiching response to the transient model start-up. In this case, the oscillation is a free motion which gradually dies away due to the effect of bottom friction (as well as numerical dispersion). As mentioned in section 3.4, this type of response can be reduced by a gradual build-up of the incident wave height.

Results for a longshore current on a plane beach are shown in Figure 5-5, for the linear model and no lateral mixing, and in Figure 5-6, for the nonlinear model with mixing. The two solutions clearly represent the behavior predicted by the theoretical solutions, with the exception that the sharp decay in velocity at the breaker line predicted by the solution with no mixing is spread over several grid spaces in the linear model due to the use of finite grid squares. This effect can be reduced by the use of a finer grid spacing.

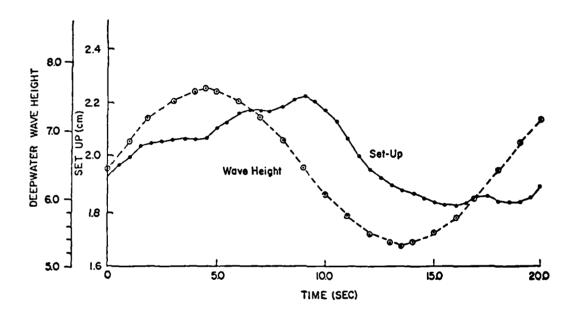


Figure 5-2. Set-up at Shoreline due to a Wave Group with 18 second period.

Linear Model

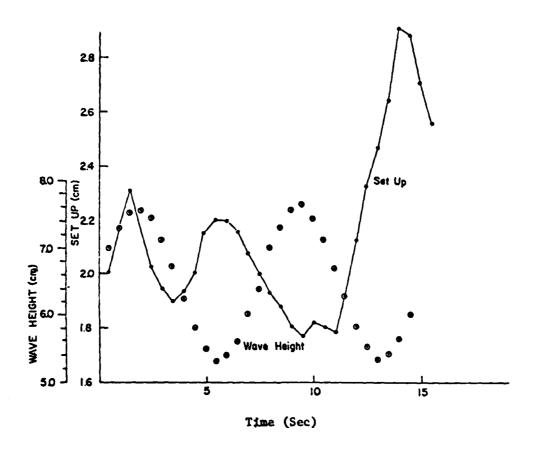


Figure 5-3. Resonance of Wave Channel Due to Forcing at Seiche Period

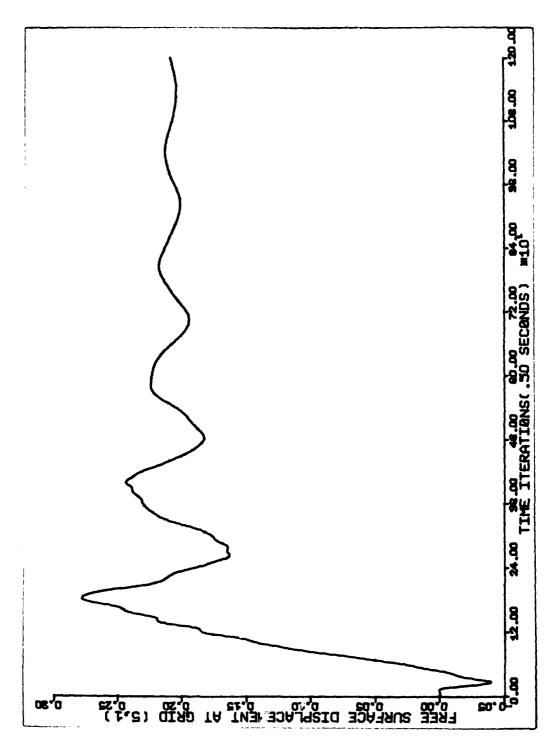


Figure 5-4. Inshore Mean Free Surface Displacement Versus Time for the Non-Linear Model Application to a Plane Beach

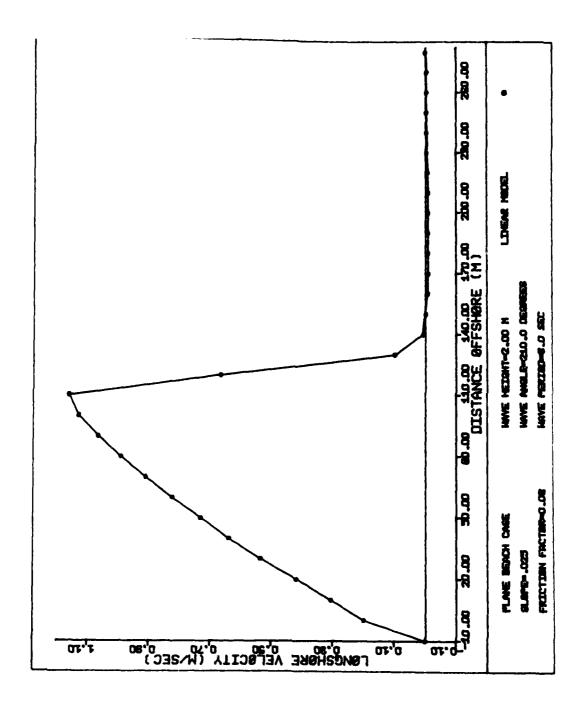


Figure 5-5. Longshore Current Profile for Plane Beach Linear Model

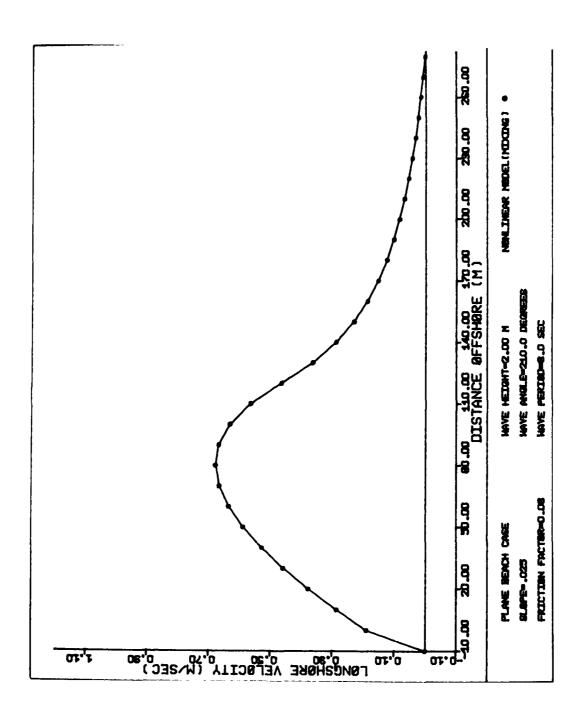


Figure 5-6. Longshore Current Profile for Plane Beach including
Lateral Mixing
Nonlinear Model

The applications discussed here indicate that the model accurately reproduces the available analytic solutions for simplified physical situations.

# 2.2 Barred Profile Applications

In nature, beaches are often fronted by continuous or fragmented longshore bars. In order to model this situation, the nonlinear model was run using a barred profile (Figure 5-7) for the same wave conditions used to generate the plane beach results described above. For this case, the model was run neglecting the effect of lateral mixing, and including the effect; results are shown in Figures 5-8 and 5-9 respectively. The solution without lateral mixing demonstrates the major discrepancy found between theoretical solution and field data for the special case. As the model wave passes the crest of the offshore bar, it stops breaking since it responds instantaneously to the local bottom. In the absence of lateral mixing, no currents are generated in the trough between shore and bar. This result is in disagreement with field observation as shown recently by Allender et al. (1981) as well as other investigators. The inclusion of lateral mixing effects partially alleviates this discrepancy.

Two factors may contribute to the observations that currents in natural surf zones tend to be strongest in the trough between bar and shore. First, fragmented bars tend naturally to induce two dimensional flow patterns characterized by rip currents flowing seaward at the gaps in the bar system. These currents are driven by longshore variations in the set-up resulting from interaction between the incident waves and the non-uniform topography.

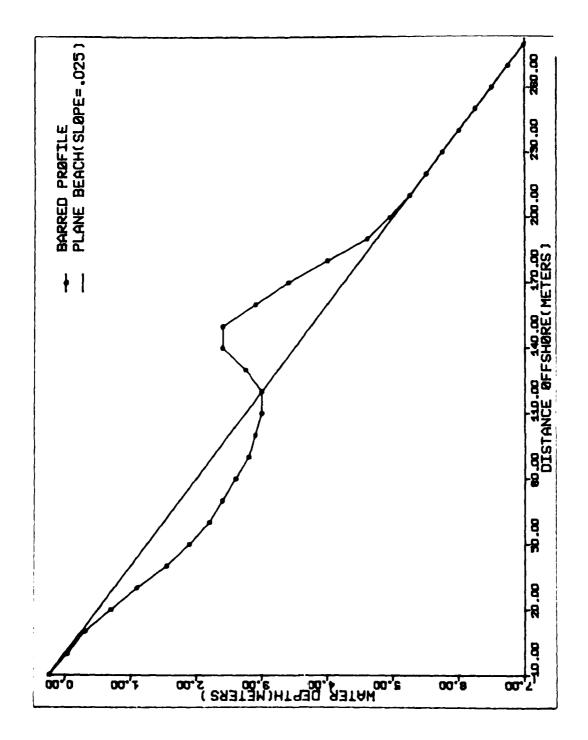
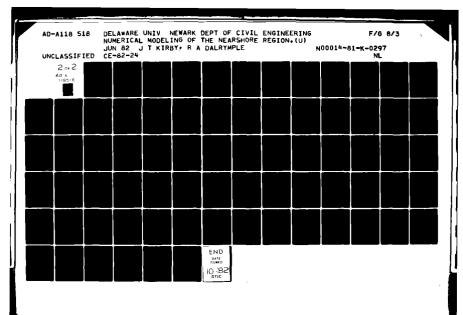


Figure 5-7. Barred Profile used for Results in Figures 5-8, 5-9.



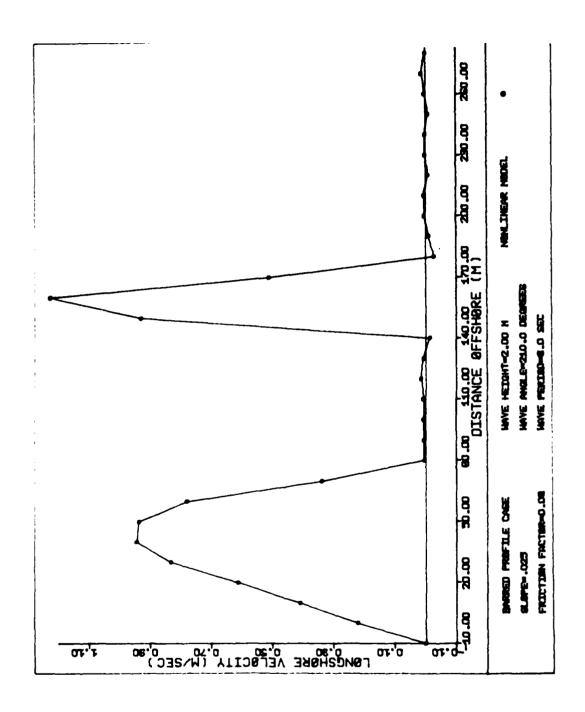


Figure 5-8. Longshore Current for Barred Profile Nonlinear Model, No Lateral Mixing

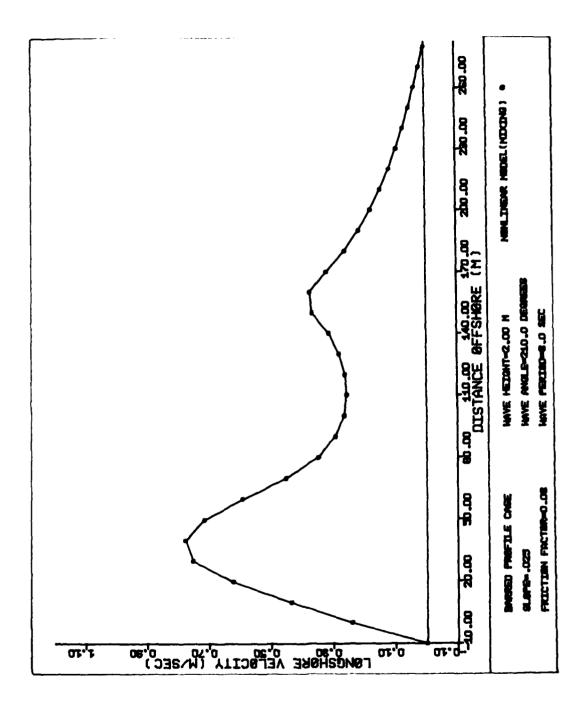


Figure 5-9. Longshore Current for Barred Profile Nonlinear Model, Lateral Mixing Included

In these situations, currents flowing along the beach are driven by gradients in the mean water surface; the flow is naturally higher in the trough, where hydraulic resistance is lower. This mechanism for rip current maintenance has been discussed by Dalrymple (1978). It is possible that this mechanism will always bias the currents observed on real beaches.

The second possibility perhaps lies in the standard treatment of surf zone wave height as a function only of the local depth. The process of wave breaking initiates a turbulent flow pattern which is certain to have some time dependence, at least in its decay. A model for spilling breakers including this effect has been discussed by Longuet-Higgins and Turner (1974). It is possible, then, that an accurate picture of currents on a barred profile would require the inclusion of a continuation of wave energy decay in a time dependent manner past the joint where the wave stops shoaling. Wave energy decay models have been used successfully by Divoky, LeMehaute and Lin (1970) in a study of wave height decay in the surf zone, and by Miller and Barcilon (1978) in a study of rip currents. However, present models do not allow for the cessation of breaking, which is required if the process of wave breaking and reformation is to be successfully treated.

# 2.3 Applications to the Laboratory Wave Basin

In order to model currents in a laboratory wave basin, the linear model described here was modified to include no flow boundary conditions at the longshore boundaries. (This option is not included in the present model.) Model tests were conducted to numerically approximate the experimental set-up and analytic theory of Dalrymple et al. (1977). In the physical experiment,

a plane beach was established at an angle of 15° to a flap-type wavemaker. Waves approached the beach over a flat bottom until they reached the front of the beach slope, where refraction effects began. Three cases were tested experimentally and theoretically; here, we restrict our attention to the case where the surf zone is bounded laterally by walls extending to infinity in the offshore direction. Experimentally determined streamlines are shown in Figure (5-10), in comparison to the analytic solution. In the numerical model, the physical situation was altered by extending impermeable walls in a direction normal to the beach; the waves, however, are allowed to propagate freely according to refraction governed by an infinite beach. The numerical model corresponded to the conditions used to develop the analytic solution. Velocity vectors calculated by the linear model are shown in Figure (5-11), in mirror image to the geometry in Figure (5-10). Longshore current velocities calculated by the linear model are compared to experimental values in Figure (5-12). The model is seen to underpredict currents in comparison to the analytic and experimental results.

## 2.4 Periodic Bottom Topography

In a study of rip currents caused by submerged on-offshore channels, Noda (1970) developed an equation for the depth which produces a channel oriented at an angle to the beach. The present models were tested using Noda's periodic bottom, given by

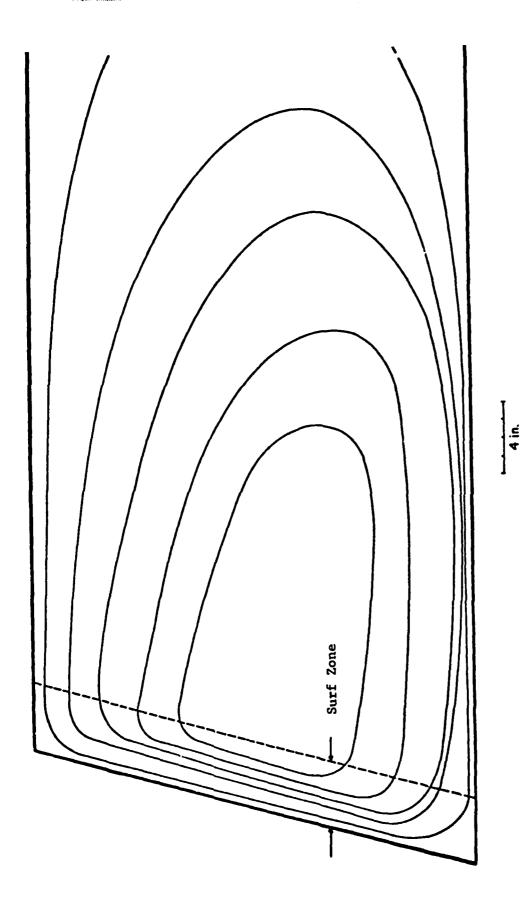


Figure 5-10. Experimental Strealines in the Wave Basin [From Dalrymple et al. (1977)].

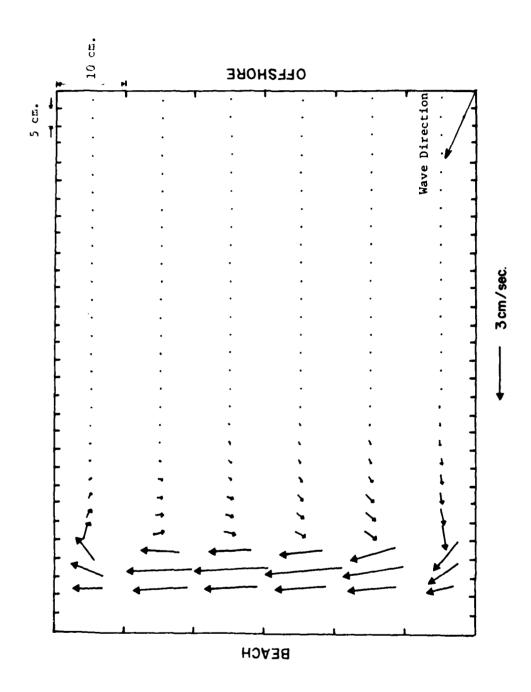


Figure 5-11. Calculated Velocity Vectors for Closed Basin Corresponding to Experimental Results of Figure 5-10

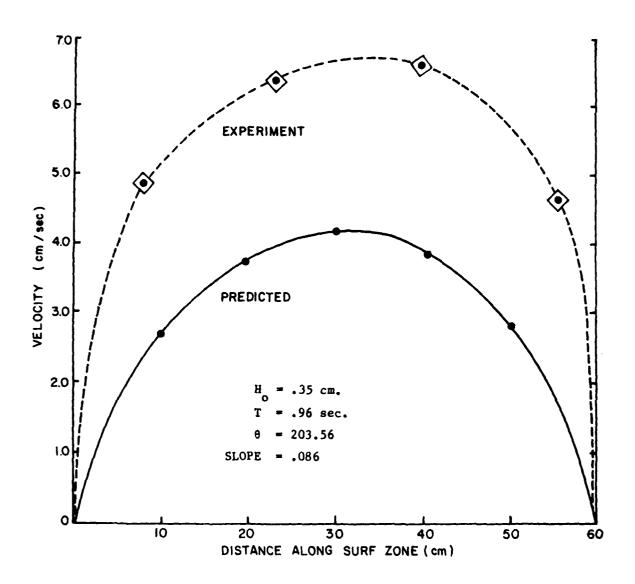


Figure 5-12. Predicted and Measured Longshore Velocities for the Closed Basin Test Case.

Linear Model.

$$D_{i,j} = \begin{cases} -m(4-i)\Delta x & i = 1,2,3,4 \\ \\ m\Delta x\{1+A \exp[-3(\frac{x}{20})^{1/3}]\sin^{10}\frac{\pi}{\lambda} (y-x \tan \beta)\} & i > 4 \end{cases}$$

where

x, y are coordinates of grid (i,j)

m = average beach slope = 0.025

 $\lambda$  = length of periodicity = 70 m

A = amplitude of bottom variation = 20

 $\beta$  = angle of rip channel to beach normal = 30°

The test contours are shown in Figure 5-13. The bottom topography was intended to model a field case studied by Sonu (1972). Current vectors calculated using the linear model are shown in Figure 5-14; current magnitude agree well with the field data reported in Noda et al. (1974), and are higher than the currents calculated in Noda et al.'s model, in which only 50% of the calculated current is used in determining the wave number due to numerical instability problems.

The Noda profile was also tested using the nonlinear model with lateral mixing (Figure 5-15). The effect of the extra terms modelled is to largely drop out the rip current clearly seen in the linear model results. Similar results have been obtained by Liu (1982), using a finite element approach, but the absence of a rip current under the given conditions is clearly at odds with the field data of Sonu (1972).

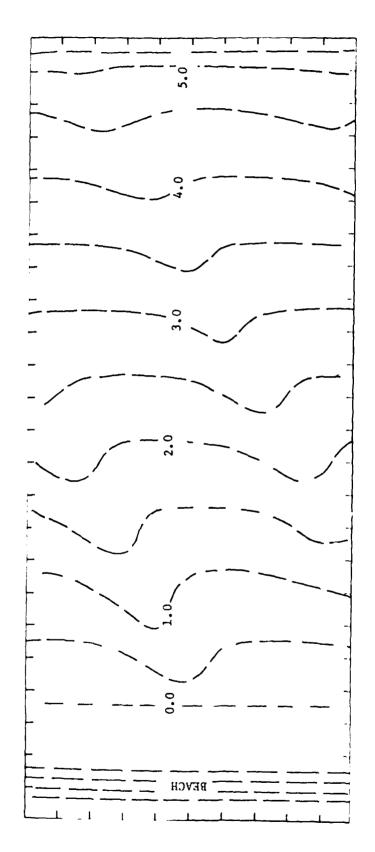


Figure 5-13. Depth Contours for the Periodic Bottom Due to Noda (1973).

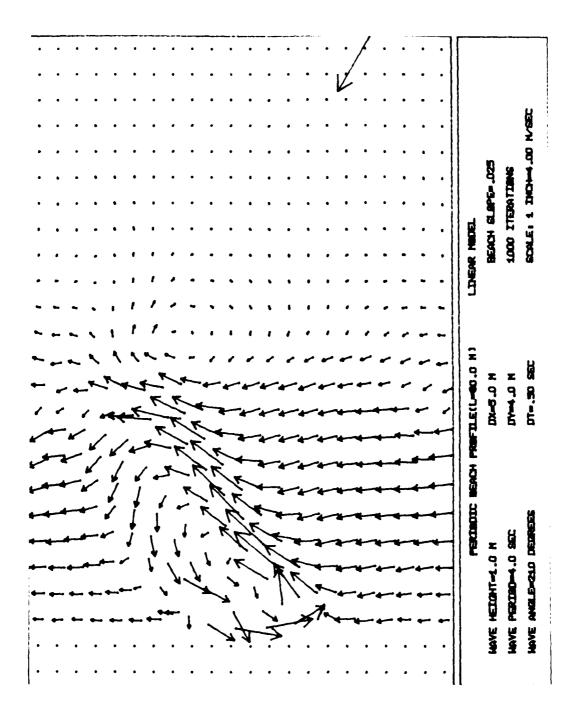


Figure 5-14. Current Vector Plot for Bottom Topography of Noda.

Linear Model, No Lateral Mixing.

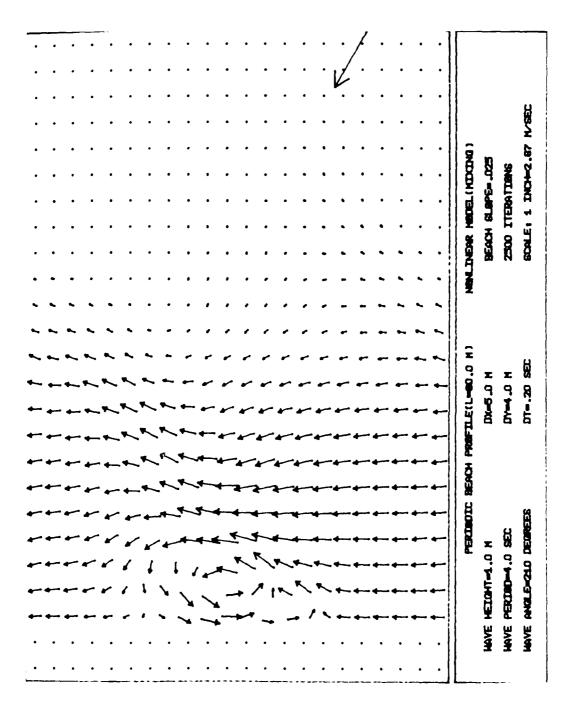


Figure 5-15. Current Vector Plot for Bottom Topography of Noda.
Nonlinear Model, Lateral Mixing Included.

A second periodic topography has been investigated for the present study. It is well established that the presence of a nearly shore-normal channel deeper than the surrounding beach slope will tend to induce a rip current, with flow directed offshore in the channel. For the present case, a longshore-periodic perturbation consisting of a localized bulge, or relatively shallow region, has been added to an otherwise planar beach profile. The bottom is given by the relation

$$D_{i,j} = \begin{cases} -\pi & (2-i) \le x & i = 1 \\ m(i \le x)(1-0.9 \cos^6 \left\{ \frac{j}{(N-1)} \right. \pi \right\} \exp(-0.015 i \le x) & i = 1 \end{cases}$$

where

Results using both models are shown in Figures 5-16 and 5-17. The effect of the inclusion of convective acceleration terms in the nonlinear model is not apparent in the results, which may be a result of the counterbalancing effect of lateral mixing. The lateral mixing effect can be seen in the shoremost grid row. The overall effect modelled here can be explained most simply in terms of a longshore imbalance in the steady state set-up. As the bulge concentrates wave energy by refraction, a region of relatively high breaking waves is created. As water is pumped on shore by the gradient of the onshore radiation stress, a localized region of high set-up is created; this region in turn pumps the onshore-flowing water alongshore into the regions of low set-up. The waves over the region of the bulge then must continuously pump water onshore in an attempt to fill the surf zone up to the

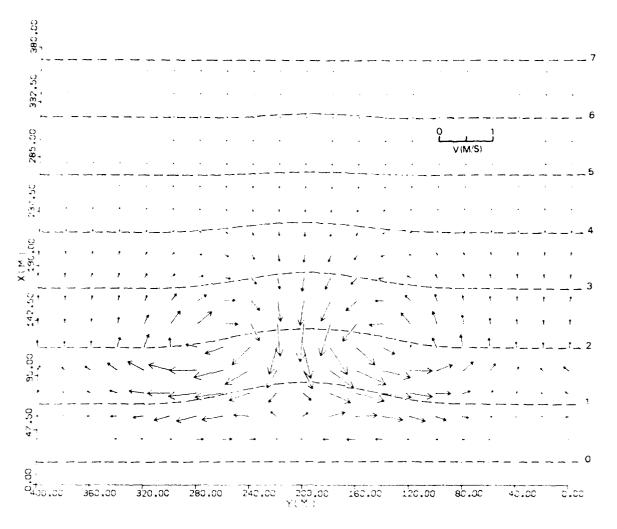


Figure 5-16. Currents Induced by Bulge on a Plane Beach Linear Model:  $T = 10.0 \text{ s, } H_0 = 1.0 \text{ m, } \theta_0 = 180^{\circ}.$ 

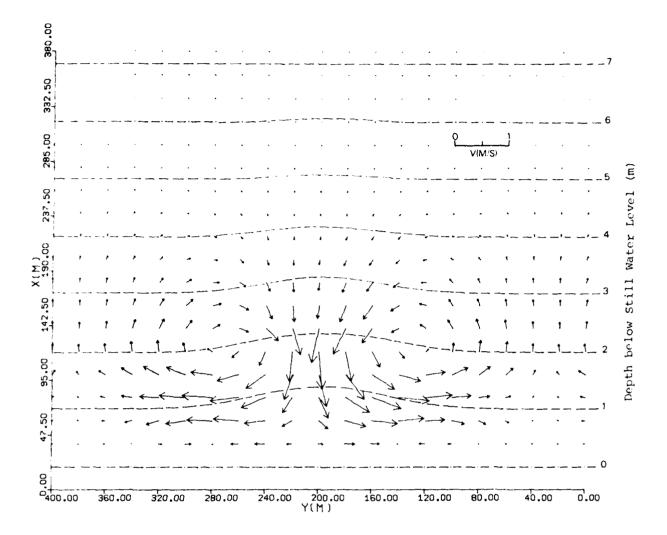


Figure 5-17. Currents Induced by Bulge on a Plane Beach Nonlinear Model:  $T = 10.0 \text{ s}, H_0 = 1.0 \text{ m}, \theta_0 = 180^{\circ}.$ 

level determined by the decay of wave energy, leading to a steady state circulation pattern.

# 2.5 Intersecting Waves Application

Ebersole and Dalrymple have discussed the application of the model to the case of intersecting wave trains of the same frequency on a plane beach, which provides a mechanism for generating rip currents, as shown by Dalrymple (1975). The purpose of this application was to investigate the effect of the convective acceleration terms in the model. The following derivation closely follows the work of Dalrymple.

Given two intersecting wave trains A and B with amplitudes a and b and a common frequency,  $\sigma$ , in terms of the coordinate system shown in Figure 5-18, the free surface displacements for the two wave trains can be written as,

$$\eta_A = a \cos(k \cos \alpha x + k \sin \alpha y + \sigma t)$$
 $\eta_B = b \cos(k \cos \beta x + k \sin \beta y + \sigma t)$ 

Figure 5-18. Wave Angles for Intersecting Waves.

The total free surface  $\eta_T = \eta_1 + \eta_2$  can then be written as,

$$\eta_{T} \approx 2a \cos \left\{ \frac{k}{2} (\cos \alpha + \cos \beta) x + \frac{k}{2} (\sin \alpha + \sin \beta) y + \sigma t \right\} \cdot$$

$$\cos \left\{ \frac{k}{2} (\cos \alpha - \cos \beta) x + \frac{k}{2} (\sin \alpha - \sin \beta) y \right\}$$

$$+ (b-a) \cos \left\{ k \cos \beta x + k \sin \beta y + \sigma t \right\} . \tag{5.2}$$

Using the linearized dynamic free surface boundary condition the velocity potential  $;_{\rm T}$  can be shown to equal,

From the velocity potential the total orbital velocities can be found from,

$$u = -\frac{\partial \phi}{\partial x}$$
 ,  $v = -\frac{\partial \phi}{\partial y}$  ,  $w = -\frac{\partial \phi}{\partial z}$  .

The radiation stresses, which are essentially the forcing terms, are defined as,

$$S_{xx} = \int_{-h}^{0} \overline{\rho u^{2}} dz + \int_{-h}^{n} \overline{P} dz - \frac{1}{2} \rho g (h+\overline{\eta})^{2} + \frac{1}{2} \rho g \overline{\eta^{2}}$$

$$S_{yy} = \int_{-h}^{0} \overline{\rho v^{2}} dz + \int_{-h}^{n} \overline{P} dz - \frac{1}{2} \rho g (h+\overline{\eta})^{2} + \frac{1}{2} \rho g \overline{\eta^{2}}$$

$$S_{xy} = \int_{-h}^{0} \overline{\rho u v} dz$$

where

$$\overline{P} = \rho g(\overline{n} - z) + \frac{\partial}{\partial x} \int_{z}^{0} \overline{\rho u w} dz + \frac{\partial}{\partial y} \int_{z}^{0} \overline{\rho v w} dz - \overline{\rho w}^{2} .$$

The radiation stresses are found to be given by

$$S_{xx} = \frac{\rho g}{4 \sinh 2kh} \left[ a^2 \cos^2 \alpha + b^2 \cos^2 \beta + 2ab \cos \alpha \cos \alpha \cos (2\psi) \right] \cdot \left\{ 2kh + \sinh 2kh \right\} - \frac{\rho g}{8 \sinh 2kh} \left( \cos \beta - \cos \alpha \right)^2 \cos (2\psi) \cdot \left\{ 2kh \cosh 2kh + \sinh 2kh \right\} - \frac{\rho g}{8 \sinh 2kh} \left( \sinh - \sin \alpha \right)^2 \cos (2\psi) \cdot \left\{ 2kh \cosh 2kh + \sinh 2kh \right\} - \frac{\rho g}{4 \sinh 2kh} \left[ a^2 + b^2 + 2ab \cos (2\psi) \right] \cdot \left\{ \sinh 2kh - 2kh \right\} + \rho gab \cos^2 \psi + \frac{1}{4} \rho g(b-a)^2$$

$$S_{yy} = \frac{\rho g}{4 \sinh 2kh} \left[ a^2 \sin^2 \alpha + b^2 \sin^2 \beta + 2ab \sin \alpha \sin \beta \cos (2\psi) \right] \cdot \left\{ 2kh + \sinh 2kh \right\} - \frac{\rho g}{8 \sinh 2kh} \left( \cos \beta - \cos \alpha \right)^2 \cos \left\{ 2\psi \right\} \cdot \left\{ 2kh \cosh 2kh + \sinh 2kh \right\} - \frac{\rho g}{8 \sinh 2kh} \left( \sin \alpha - \sin \beta \right)^2 \cos \left\{ 2\psi \right\} \cdot \left\{ 2kh \cosh 2kh + \sinh 2kh \right\} - \frac{\rho g}{4 \sinh 2kh} \left[ a^2 + b^2 + 2ab \cos \left\{ 2\psi \right\} \right] \cdot \left\{ \sinh 2kh - 2kh \right\} + \rho gab \cos^2 \psi + \frac{1}{4} \rho g(b-a)^2$$

$$S_{xy} = \frac{\rho g}{4 \sinh 2kh} \left[ a^2 \sin \alpha \cos \alpha + b^2 \cos \beta \sin \beta + ab \cos \left\{ 2\psi \right\} \sin \left(\alpha + \beta \right) \right] \cdot \left\{ \sin \alpha + \beta \right\}$$

{2kh+sinh2kh}

where the expression " $\psi$ " is defined as,

$$\Psi = \frac{k}{2}(\cos\alpha - \cos\beta)x + \frac{k}{2}(\sin\alpha - \sin\beta)y$$

The time independent mean free surface displacement,  $\overline{\eta}$ , is defined by

$$\overline{\eta} = -\frac{1}{2g} \overline{\{u^2 + v^2 + w^2\}}_{z=0}$$

where "---" denotes the time average over one wave period. Substituting the expressions for the velocity components u, v, and w from the velocity potential  $\frac{1}{4\pi}$ ,  $\frac{1}{4\pi}$  can be written as,

$$\frac{1}{\eta} = \frac{-k}{2\sinh 2kh} \left[ a^2 + b^2 + 2ab\cos(2\psi) \cdot (\cos(\alpha - \beta)\cosh^2 kh - \sinh^2 kh) \right]$$
 (5.3)

where " $\psi$ " is the same quantity defined previously. Notice that the mean free surface displacement is modulated in the x and y directions by,

$$cos\{k(cos\alpha-cos\beta)x + k(sin\alpha-sin\beta)v\}$$

Using Snell's Law which states

$$k_0 \sin \alpha_0 = k \sin \alpha$$
 and  $k_0 \sin \beta_0 = k \sin \beta$ ,

and using the fact that  $k_0 = \frac{2\pi}{L_0}$ , where "o" denotes deep water values for the wave length, L, and the wave angles,  $\alpha$  and  $\beta$ , we see that there is a periodicity of the mean displacement in the longshore direction with a periodic spacing,  $\ell$ , given by,

$$\ell = \frac{L_0}{\sin \alpha - \sin \beta_0}$$

This periodicity in water level and wave height causes water to be driven from regions of high mean water level displacement to regions of lower displacement, resulting in the formation of circulation cells.

In order to attempt to model this phenomena, certain simplifications to the model had to be made. Since the refraction and shoaling routines borrowed from the work of Noda, et al., could not treat more than one wave train, they were replaced with routines governed by Snell's Law neglecting wave-current interaction. Again a quadratic, "exact," bottom friction was used including velocities due to mean currents and, this time, the two wave trains. In the momentum equations the advective acceleration terms were retained, horizontal mixing was neglected, and the radiation stresses were calculated using the results presented earlier in this section. The wave height used in calculating the radiation stresses and the bottom frictional stresses is given by

$$H_{T} = 2.0 \sqrt{a^{2}+b^{2}+2ab \cos[k(\cos\alpha-\cos\beta)x + k(\sin\alpha-\sin\beta)y]}.$$

Two runs are presented here using different combinations of wave heights and wave angles. The remainder of the input data for both runs, however, was the same. The waves were run on a plane beach with a slope of 0.025. The planform area of interest was comprised of 25 grids in the x direction with an  $\Delta x$  grid size of 5.0 meters, and 21 grids in the longshore direction with a  $\Delta y$  grid size of 4.0 meters. The time step was chosen to be 0.2 seconds and the model was run for 1500 iterations for both cases. A wave period of 7.159366 seconds was used, which resulted in theoretical rip spacings of 80.0 meters. The bottom friction factor was set equal to 0.12 to allow the system to reach steady state after the 1500 iterations and to decrease the magnitude of the resultant currents.

The first case used waves of equal heights and equal angles to either side of the beach normal. The deep water wave heights were 0.25 meters and

the deep water angles were  $\pm$  30.0 degrees. For this case, referring to Eq. (5.3),  $\alpha = \beta$  and  $\alpha = -\beta$  resulting in a free surface displacement given by

$$n_{T} \approx 2a \cos(k_{o} \sin \alpha_{o} y)\cos(k \cos \alpha x + \alpha t)$$
.

This free surface describes a wave train moving in the -x direction with a modulated wave height that is periodic in the longshore direction only. The periodicity in wave height is the driving mechanism producing the rip current perpendicular to the beach, as shown in Figure 5-19. Note the constricted width of the rip current in relation to the width of the inflow region. This is a result of the convective acceleration terms. Also note the weak rip head where the currents diverge from the rip axis and return towards shore.

In the second case, the waves, A and B, had different heights, 0.1 and 0.4 meters, and wave angles of 30.0 and -30.0 degrees, respectively. The resulting circulation pattern is shown in Figure 5-20, and consists of a meandering current with alternating regions of strong and weak long-shore velocity along the beach. This circulation would lend itself well to the formation of rythmic beach features. Looking at Eq. (5.2), we see that there is a non-zero term,

$$(b-a)\cos\{k\cos\beta x + k\sin\beta y + \sigma t\}$$

which is a wave train at an angle to the beach normal with height 2(b-a). This wave is present in addition to the normal wave train with the modulated height from the first case, causing a longshore current which is superimposed on the cellular circulation.

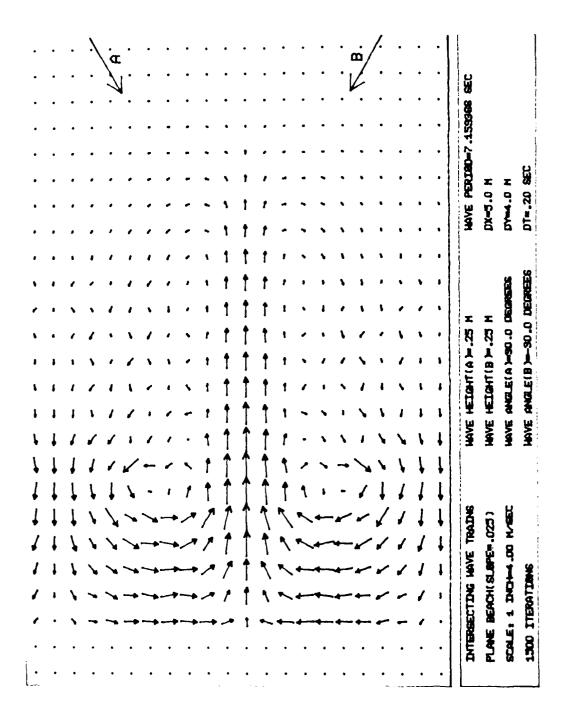


Figure 5-19. Current Vector Plot for Intersecting Waves, Case 1.

Nonlinear Model

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Figure 5-20. Current Vector Plot for the Meandering Circulation Pattern. Nonlinear Model.

# Chapter VI

### CONCLUSIONS

In this report, the theoretical background and numerical formulation of two models for nearshore circulation have been reviewed. A review of the application of the models to plane beach problems has shown that the models successfully reproduce the characteristics of known analytic solutions. The comments of Basco (1981), who expressed the opinion that the models are invalid due to the effect of numerical viscosity on the calculated velocity profiles, can be seen to be incorrect upon inspection of Figure 5-5, which demonstrates the steep drop in longshore current at the breaker line in the absence of a prescribed lateral mixing. In addition, Figure 5-1 shows that the model reproduces the sharp drop in wave set down at the breaker line, further indicating that the model is capable of reproducing the distinct features of analytic solutions, if the grid scheme chosen is fine enough to resolve the features. It is apparent that any numerical diffusion of solutions for  $\overline{\eta}$  or V is confined to one or two grid rows, and can be made insignificant by choosing the grid size small enough. It should also be remarked that the slight decrease in the longshore velocity below the purely linear profile predicted by Longuet-Higgins (1970a) has been explained to be a result of wave-current interaction (Dalrymple, 1980) included in both models, and of finite angle of wave incidence (Liu and Dalrymple, 1978; Krauss and Sasaki, 1979), included in the nonlinear model. In conclusion, there appears to be no discrepancy between numerical solutions using a fine grid and the corresponding analytic solutions.

In practical applications, grid spacings are often chosen which lead to some false numerical averaging of the solutions. In the linear model, this averaging manifests itself most obviously as a smoothing of the long-shore profile across the breaker line in the same manner as would be induced by lateral mixing effects (see Figure 4-14). This indicates that the mixing coefficients included in the nonlinear model should be smaller than expected on physical grounds in order to compensate for the numerical effects. With the choice of a friction factor based on the formulae of Jonsson (1966) or Kajiura (1968), the model is then seen to produce realistic current profiles, both in form and magnitude, for the field site chosen. However, it should be noted that no detailed data set currently exists which satisfies the requirement of a monochromatic input wave condition, and which represents a field case for which model results are fairly reliable, such as the absence of a large longshore bar.

The numerical models are shown to be successful predictors of nearshore dynamics in situations dominated by refraction and weak wavecurrent interaction effects. In this regard, it is noted that the model as currently formulated cannot handle certain effects, such as the influence of finite barriers in the wave field, or strong interaction of waves and opposing currents. The modelling of both of these effects requires the inclusion of a capability for handling wave diffraction.

Finally, the present models require an input wave condition based on a monochromatic wave, whereas wave trains in nature tend to include a spectrum of waves. In the case where the incident wave spectrum is sufficiently narrow-banded in frequency, the incident wave can be represented as a wave of single frequency with a modulated amplitude; such an effect can

be modelled after modification of the programs to handle a time varying deepwater wave height. However, modelling of broad-banded spectra at the level of the treatment here remains a complex problem.

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### Appendix I.

#### USING THE NEARSHORE CIRCULATION PROGRAM

The nearshore circulation model as described above is supplied in two versions, referred to as the linear and the nonlinear versions. Complete listings of the programs for each version follow. The programs as written are designed to run on a Burroughs B7700. The line

#### SRESET FREE

which appears on the front of each program allows for the use of standard Fortran on the B7700. This line should be removed before operating the program on a different system.

The two versions of the model are currently designed to be indistinguishable to the operator, with the input file containing wave and wind information and the depth grid being of identical format for each program. The output file generated currently at a line printer is also identical for each program. The exception to the uniformity between the two models occurs in the output file stored at the end of execution for subsequent restart of the model. Since the nonlinear version of the program requires the storage of three time levels of data, two extra time levels are included in the output. Thus, the nonlinear version of the program can not be started based on intermediate results generated by the linear version, as not enough information is present. It is possible in principle to start the linear version of the program using intermediate results from the nonlinear version, although at present the READ statement in the linear version is not structured to handle this option.

The circulation model is currently designed to be run as a batch job, and as such has all device number specifications for data files in the job file external to the program. This feature may have to be changed depending on the machine to be used. Currently, data files may be named arbitrarily. The program currently requires four IO device specifications:

Logical Device Number	Corresponding Data File
5	User defined input data
6	Output stream, currently directed to a line printer
3	Output file, stores results of last interation for a later restart
8	Input file used to restart the model

It should be noted that the input file 8 used for restarting the program is identical to, and should be just a renamed version of, the output file 3 generated by the model at the point from which it is desired to continue computation.

## Structure of Input Data File 5

The input data file is structured into five groups of data. The first four groups each consist of a single line in the file, with data values entered unformatted; i.e., separated by commas with no requirements on spacing. The fifth data group consists of the depth grid, and requires more space than a single line, as explained below. The information included in the input data file is as follows.

#### DATA IN INPUT DATA FILE 5

#### 1. Wave Parameters

T - Wave period (seconds)

HO - Wave height (meters)

A - Wave angle, measured clockwise from the +X direction (degrees)

#### 2. Wind Parameters

WIND - Wind speed (meters/second)

WINANG - Wind angle, measured clockwise from the -X direction (degrees)

#### 3. Grid Parameters

M - Number of grid rows in X direction (offshore)

N - Number of grid columns in Y direction (longshore)

DX - Grid spacing in X direction (meters)

DY - Grid spacing in Y direction (meters)

DT - Size of the time step (seconds)

INDEX - Specifies the input of depth information
=1, read data from previous run from file 8

=2, read depth grid from input file 5

=3, establish plane beach based on input beach slope

AM - Beach slope (space in input file must be filled, but value is unsed only if INDEX=3)

## 4. Program Control Parameters

Total number of iterations (including the accumulated total from previous runs, if previous run data is used)

NHIGHT - Number of iterations over which the deep water wave builds up

ID - Determine if dissipation of wave energy is to be
included
=0, no dissipation
=1, dissipation due to viscosity and bottom permeability

=1, dissipation due to viscosity and bottom permeability is included

KSKIP - Determine frequency of printed iterations in output file 6

5. Depth Grid (required if INDEX=2)

D - Local water depth with respect to still water level at each grid center.

The depth grid D is input in an unformatted string of length M\*N, starting with the fifth line of the input file 5 and continuing to as many lines as necessary. The data values are read off of an established grid row-wise in the +Y direction, starting at the inshore end of the grid.

## Coordinate System Used in the Program

The input depth grid and wave and wind parameters should be established using the coordinates shown in Figure 2-1. The models require that the bathymetry be periodic in the longshore direction. Accordingly, for an input depth grid of size (M, N), where (I, J) are X and Y indices and (M, N) are the maximum values of (I, J), the laterally bordering depth values should satisfy the requirement:

$$D(I,N) = D(I,1) .$$

If this condition is not met on input, D(I,1) is redefined to be equal to D(I,N). Both models create two additional rows in the Y direction, (N+1) and (N+2). The grid storage requirement for all variables is thus M by (N+2), with a current

maximum of 50 by 50. The maximum may be enlarged or decreased by alteration of  $\underline{\text{all}}$  COMMON and DIMENSION statements in either program.

Wave angle and wind angle are defined as shown in Figure 2-1. Wave angle is measured clockwise from the +X direction. Waves approaching the beach from the right of directly offshore have wave angles > 180°. Wind angle is given clockwise from the -X direction, so that winds approaching shore from the right of normal have wind directions greater than 0°.

The program requires that incident waves have longshore components propagating in the +Y direction. For the case of wave angles =  $180^{\circ}$  -  $\theta$ , the program flips the depth grid over and rotates the wave and wind directions through  $360^{\circ}$  -  $2\theta$  degrees, and runs the program for waves approaching at  $180^{\circ}$  +  $\theta$  and a mirror image depth grid.

## Error Messages from the Circulation Models

Each version of the nearshore circulation model will generate various error messages when fatal conditions are met during execution. The messages are, for the most part, identical from either program and correspond to equivalent situations within the programs. A list of possible internally occurring errors leading to the printing of a message follows.

1. Failure of iteration scheme to converge on a wave height at a grid point will cause the message

RELAXATION FOR THE WAVE HEIGHT FAILED TO CONVERGE

followed by an indication of the row and number of iterations tried. This

condition arises in the subroutine HEIGHT. Occurrence of the condition does not lead to termination of the program; iteration continues with the last wave height calculated and the entire iteration is tried again at the next time step.

2. Failure of iteration scheme to converge on a wave angle at a grid point will cause the message

## RELAXATION FOR THETA FAILED AFTER -- ITERATIONS

with an indication given of the number of iterations tried. This condition could arise if the magnitude of a current directed against the general direction of wave travel was too strong. The condition arises in the subroutine ANGLE and causes termination of the program.

3. If a negative wave number RK is calculated, the message

## RK IS NEGATIVE

is printed, and the program is terminated. This condition occurs in the subroutine WVNUM.

LINEAR MODEL

	\$RESET FREE	00010000
	* NEARSHORE CIRCULATION MODEL LINEAR VERSION	00010020
10040	THIS COMBUTED DESCRANTS A NUMERICAL MODEL TO DREDICT SUBE-ZONE	00010040
	DYNAMICS, GIVEN A FIXED,	0001000
	MONOCHROMATIC WAVE CONDITIONS AS INPUT.	00010070
10080	THE REFRACTION PROGRAM INCLUDING WAVE-CURRENT	00010080
	DEPOSE NOT THE PROCESS OF THE MODEL DEVEL DEVEL	0010100
		00010110
		00010120
10130 C		00010130
0140	COMMON D(50,50),U(50,50),V(50,50),Z(50,50),SI(50,50),CU(50,50), ************************************	00010140
0160	**************************************	00010160
10170	COMMON/VAL/ETA(50,50)	00010170
10180	COMMON/STRESS/SIGXX(50,50), SIGYY(50,50), SIGXY(50,50), TAUBX(50,50),	00010180
10190	*TAUBY(50,50),TAUSX(50,50),TAUSY(50,50)	00010190
0200	COMMON/REF/ZZ(50,50),HNEW(50,50),RKA(50,50)	00010200
0220	* N N N N N N N N N N N N N N N N N N N	0001030
10230	DIMENSION DST(50,50)	00010230
10240 C		00010240
10250		00010250
10240	NOTED ON ROBING THE CIRCOLATION VACGRAM	0001020
	* 1. WAVE ANGLE IS MEASURED CLOCKWISE FROM THE +X DIRECTION	00010280
		00010290
10300	2. WIND ANGLE IS MEASURED CLOCKWISE FROM THE -X DIRECTION	00010300
	* 3 ALL INPLIT AND CLITCH DATA IS IN MKS LINITS	00010310
	;	00010330
	4	00010340
10350 C*	FIELDS	00010350
		00010380
		00010370
10390 C	<ul> <li>DEFINITIONS OF QUANTITIES USED IN PROGRAM</li> </ul>	00010390
10400 C*		00010400
	1. CONSTANTS	00010410
10420 C*	CHUY VORIA) GOTTON FRITCH ACTION ( PARTY VORIA)	00010420
	2 2	00010430
		00010450
	<ul> <li>2. VARIABLE ARRAYS (VALUE AT EACH GRID LOCATION)</li> </ul>	00010460
10470 C*		00010470
	D - TOTAL WATER	00010480
10490 C*	ETA	00010490
00000	WAVE ANGLE	00010500
	3:	00010910
10530 C*	31	00010920
		00010540
		00010550
	* IB=O, WAVE IS BREAKING LOCALLY	00010560
10570 C*	18=1,	000 10570
10580 C	DDDX,DDDY - LOCAL DERIVATIVES OF THE TOTAL DEPTH	00010580

s H	00010670 00010680 00010680 00010710 00010720 00010730 MES 00010750 00010750 00010750	00010790 00010800 00010810 00010810 00010840 00010840 00010850 00010860 00010880 00010880 00010880 00010880 00010980	BEACH SLOPE	ATED IS WAVE BE ERM-
AUMBER LOCITIES AT SIDES OF GRID BLO LOCITIES AT SENTERS OF GRID B LOCITIES AT CENTERS A	LOCALLY DEFINED VARIABLES  LOCALLY DEFINED VARIABLES  DUDX,DVDX - VELOCITY GRADIENT COMPONANTS  DCDX,DCDY - WAVE CELERITY GRADIENT COMPONANTS  DCGDX,DCGDY - GROUP VELOCITY GRADIENT COMPONANTS  DTDX,DTDY - WAVE ANGLE GRADIENT COMPONANTS  EPS - ACCURACY VALUE USED IN THE RELAXATION SCHEME	VARIABLES TO BE READ INTO PROGRAM  1. WAVE PARAMETERS  T - WAVE PERIOD (SECONDS)  HO - WAVE HEIGHT (WETERS)  A - WAVE ANGLE, CLOCKWISE FROM +X (DEGREES)  2. WIND PARAMETERS  WIND - WIND SPEED (WETERS/SECOND)  WINNAMG - WIND ANGLE, CLOCKWISE FROM -X (DEGREES)	CLUCKWISE FROM -X AIDS IN X DIRECTION RIDS IN Y DIRECTION (N S IN Y DIRETTION (N S IN	PROGRAM CONTROL PARAMETERS  ITA - TOTAL NUMBER OF ITERATIONS (INCLUDING ACCUMULATED TOTAL OF PREVIOUS RUNS, IF PREVIOUS RUN DATA IS USED)  NHIGHT - NUMBER OF ITERATIONS OVER WHICH THE DEEPWATER WAV HEIGHT IS BUILT UP  ID - DETERMINE IF DISSAPATION OF WAVE ENERGY IS TO BE INCLUDED  *O, NO DISSIPATION  *1, DISSIPATION DUE TO VISCOSITY AND BOTTOM PERM-EABLLITY
CG - GROUP V RKA - WAVE P U,V - X,Y VE W,Y - X,Y VE NOTE I SIGXX, SIGXY, TAUBX, TAUBY	LOCALLY DEF' DUDX, DVDX - DCDX, DCDY - DCGDX, DCGY - DTDX, DTDY - EPS - ACCUR	RIABLES WAVE PAI H A WIND PAI WIND	GRID PAL	PROGRAM ITA NHIGHT .
	m <sup>°</sup>	A +	က်	4
********		i 000000000000000000000000000000000000		
10590 10600 10610 10620 10630 10640 10650	10680 10680 10680 10700 10710 10730 10740 10760 10760	10790 10800 10820 10830 10830 10850 10880 10880 10990 10990	10920 10930 10930 10950 10980 11000 11020 11030 11040	11111111111111111111111111111111111111

C - D - LOCAL WATER DEPTH WATER LEVEL. 000011230 C - D - LOCAL WATER DEPTH WATER LEVEL. 000011230 C - D - LOCAL WATER DEPTH WATER LEVEL. 000011230 C - D - LOCAL WATER DEPTH D		THE COURT OF THE CASE OF THE C	
### CONSTANTS  ### CO	0		
### ### ### ### ### ### ### ### ### ##			0001126
P13: 44:9927 P13: 44:9927 P13: 44:9927 P13: 44:9927 P13: 49:902 P14: 40:902 P15: 40:902 P1	 		
RAD=180. () FILE 2. *PI RAD=180. () FILE 3. *PI RAD=180. () FILE 4. *PI RAD=180. () FILE 4. *PI RAD=180. () FILE 5. *PI RAD=18	PI=3.1415927		
FED   ThO   TO   TO	PI2=2.*PI RAN=180 O/PI		
NEAD INPUT DATA   NEAD   NEA	CF=0.015		
WAVE PARAMETERS	0.0=00		<b>*</b> •
1. WAVE PARAMETERS  READ(5./) T. T.40.A  2. WIND PARAMETERS  READ(5./) WIND. WINNAG  3. GRID PARAMETERS  READ(5./) WIND. WINNAG  READ(5./) ITA.NHIGHT. ID.KSKIP  WRITE (101) DATA ON OUTPUT FILE AS HEADER  WRITE (5.119) T. HO.A.M  WRITE (6.119) T.	1 1 (		0001138
READ(5 // ) T HO A  2. WIND PARAMETERS READ(5 // ) WIND, WINDMENTANG READ(5 // ) WIND, WINDMENTANG READ(5 // ) WINDMENTERS READ(5 // ) MINDMENT DATA ON OUTPUT FILE AS HEADER WRITE (102)M. M. ITA WRITE(6 // 103) T // 100 A, AM WRITE(6 // 103) T // 103 A, AM WRITE(6 // 103) (A // 103) T // 103 A, AM WRITE(6 // 103) (A // 103) T // 103 A, AM WRITE(6 // 103) (A // 103) T // 103 A, AM WRITE(6 // 103) (A // 103) T // 103 A, AM WRITE(6 // 103) (A // 103) T // 103 A, AM WRITE(6 // 103) (A // 103) T // 103 A, AM WRITE(6 // 103) (A // 103) T // 103 A, AM WRITE(6 // 103) (A // 103) (	-	Sas	0001139
2. WIND PARAMETERS  READ(5./) WIND,			0001141
3. GRID PARAMETERS READ(5./) ITA.NHIGHT.ID.KSKIP WRITE (5.102 IM. M. TOX.) DATA ON OUTPUT FILE AS HEADER WRITE(6.103 IM. AM. AM. AM. AM. AM. AM. AM. AM. AM. A		IRS	0001142
### READ(5,/) M.N.DX.DY.DY.INDEX.AM 4. PROGRAM CONTROL PARAMETERS  READ(5,/) IA.NH.IGHT.ID.KSKIP  WRITE INPUT DATA ON OUTPUT FILE AS HEADER  WRITE(6,101)DX.DY.DT  WRITE(6,103) T.HD.A.AM  WRITE(6,119) T.HD.A.AM  WRITE(1,10,10,10,10,10,10,10,10,10,10,10,10,10		SA:	000
## ## ## ## ## ## ## ## ## ## ## ## ##		(,DY,DT,INDEX,AM	0001145
WRITE (6, 102) M. N. ITA WRITE (6, 102) M. N. ITA WRITE (6, 104) DX. OY. OY WRITE (6, 114) WIND. WINDAMINA WRITE (6, 114) WIND. WINDAMINA WRITE (6, 115) INDEX. ID WRITE (6, 116) CF. DD ITO=O HEIGHT=HO DELTAT=DT WINNAG WINNAG (RAD N2=N+2 N1=N+1 M2=N+2 N1=N+1 M2=N+2 N2=N+2 OY=5V*2 OY=5V*3 OY=5V*		OL PARAMETERS 41GHT ID KSKIP	0001146
WRITE(6, 119) T.HOL.A.M. WATE(6, 119) T.HOL.A.M. WRITE(6, 119) T.HOL.A.	-	- V	0001148
WRITE(6, 102)M.N. ITA WRITE(6, 101)DV.DV.DY.DY WRITE(6, 114) WIND.WINANG WRITE(6, 114) T.HD.A.AM WRITE(6, 114) WIND.WINANG WRITE(6, 115) INDEX.ID WRITE(6, 116) CF. DD WRITE(6, 1	1	2	
WRITE(6, 101)DX,DY,DY WRITE(6, 114) VIND,WINANG WRITE(6, 115) INDEX,ID WRITE(1, U), U=1, NZ), I=1, M), ((V(I, U), U=1, NZ), I=1, M), WRITE(6, 115) INDEX,ID WRITE(6, 115) INDEX,ID WRITE(1, U), U=1, NZ), I=1, M), ((V(I, U), U=1, NZ), I=1, M), WRITE(6, 115) INDEX,ID WRITE(1, U), U=1, NZ), I=1, M), ((V(I, U), U=1, NZ), I=1, M), WRITE(1, U), U=1, NZ), I=1, M), ((V(I, U), U=1, NZ), I=1, M), WRITE(1, U), U=1, NZ), I=1, M), ((V(I, U), U=1, NZ), I=1, M), (		ITA	-
WRITE(6, 114) WIND, WIND, WIND, WRITE(6, 114) INDEX, ID WRITE(6, 115) INDEX, ID WRITE(6, 116) CF, DD  ITD=0  HEGHT=HD  DELTAT=HD  OCCO11  WINANG=WINANG/RAD  N2=N+2  WINANG=WINANG/RAD  WINANG-WINANG-WINANG/RAD  WINANG-WINANG-WINANG/RAD  WINANG-WINANG-WINANG/RAD  WINANG-WINANG-WINANG/RAD  WINANG-WINANG-WINANG/RAD  WINANG-WINANG-WINANG/RAD  WINANG-WINANG-WINANG/RAD  WINANG-WINANG-WINANG/RAD  WINANG-WINANG-WINANG-WINANG/RAD  WINANG-WINA	WRITE(6,101)DX, D.	7,01	
WRITE(6, 115) INDEX, ID WRITE(6, 115) INDEX, ID WRITE(6, 116) CF, DD WRITE(6, 116) CP, DD WRITE(6, 116) CD WRITE(6, 116) CP, DD WRITE(6, 116) CD WRITE	WRITE(6.114) WIN	EN . C. INANG	~ -
WRITE(6,117) NHIGHT WRITE(6,116) CF.DD WRITE(6,116) CF.DD  10000  10000  HEIGHT=HO  DELTAT=DT  WINANG=WINANG/RAD  N2=N-2  N2=N	WRITE(6,115) IND	)EX, ID	
WEIGHT		IGHT	0001156
HEIGHT=HD  DELTAT=DT  WINANG=WINANG/RAD  NI=N+1  NOS=N+2  NI=N+1  NOS=N+2  NI=N+1  NOS=N+2  N	9.1.9	aa	
DELTAT=DT WINANG=WINANG/RAD WINANG=WINANG/RAD WINANG=WINANG/RAD WINANG=WINANG/RAD WINANG=WINANG/RAD WINANG=WINANG/RAD WINANG=WINANG/RAD WINANG	HE I GHT = HO		_
MYZ=N+2 NYZ=N+2 NYZ=N+2 NYZ=N+2 NYZ=N+2 NYZ=DX*2. SIGMA=PIZ/T EPS=0.01 SIGMA=PIZ/T EPS=0.01 SIGMA=PIZ/T ESTABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 GO TO (1,2,3) INDEX SIGMA=PIZ/T SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX OOO1 SIGMA=PIZ/T STABL	DELTAT*DT	9	0001160
M1=N+1 M2=M-2 M1=M-1 DX2=DX*2. DX2=DX*2. SIGM=PIZ/T ESTABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX GO TO (1,2,3) INDEX GO TO (1,2,3) INDEX GO TO (1,2,3) INDEX GO TO (1,2,3) INDEX (GO	WINANG=WINANG/KAI NO=N+0	O.	0001161
M2=M-2 M1=M-1 DX2=DX*2. DX2=DX*2. DX2=DX*2. DX2=DX*2. DX2=DX*2. DX2=DX*2. DX3=DX-1. SIGMA=PIZ/T EPS=0.01  ESTABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX  GO TO (1,2,3) INDEX  GO TO (1,2,3) INDEX  TNDEX=1, READ DATA FROM FILE 8 FOR PREVIOUS RUN OF MODEL  OOO1 *(ETA(I,J),J=1,N2),I=1,M),(((N(I,J),J=1,M), OOO1 *((X(I,J),J=1,N2),I=1,M),(((M(I,J),J=1,M), OOO1 *((X(I,J),J=1,N2),I=1,M),((((I,J),J=1,M), OOO1 *((W(I,J),J=1,N2),I=1,M),((((I,J),J=1,M), OOO1 *((W(I,J),J=1,N2),I=1,M),((((I,J),J=1,M), OOO1 *((W(I,J),J=1,N2),I=1,M),(((((I,J),J=1,M), OOO1),J=1,M), OOO1 *((W(I,J),J=1,N2),I=1,M),(((((I,J),J=1,M), OOO1),J=1,M), OOO1) *((W(I,J),J=1,N2),I=1,M),(((((I,J),J=1,M), OOO1),J=1,M), OOO1)	2 - X - X - X - X - X - X - X - X - X -		0001163
M1=M-1  DY2=DX*2.  DY2=DX*2.  DY2=DX*2.  SIGMA=PI2/T  EPS=0.01  ESTABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX  GO TO (1,2,3) INDEX  GO TO (1,2,3) INDEX  TNDEX=1, READ DATA FROM FILE 8 FOR PREVIOUS RUN OF MODEL  OOO1  *(ETA(I,J),J=1,N2),I=1,M),((V(I,J),J=1,N), (V(I,J),J=1,M), (V(I	M2=M-2		0001164
DV2=DV*2.  DV2=DV*2.  SIGMA=PI2/T  EPS=0.01  ESTABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX  GO TO (1,2,3) INDEX  GO TO (1,2,3) INDEX  TNDEX=1, READ DATA FROM FILE 8 FOR PREVIOUS RUN OF MODEL  *((ETA(I,J),J=1,N2),I=1,M),((V(I,J),J=1,N2),I=1,M),  *((U(I,J),J=1,N2),I=1,M),((V(I,J),J=1,N2),I=1,M),  *((W(I,J),J=1,N2),I=1,M),((Y(I,J),J=1,N2),I=1,M),  *((W(I,J),J=1,N2),I=1,M),((Y(I,J),J=1,N2),I=1,M),  *((W(I,J),J=1,N2),I=1,M),((Y(I,J),J=1,N2),I=1,M),  *((W(I,J),J=1,N2),I=1,M),((Y(I,J),J=1,N2),I=1,M),			0001165
SIGMA=PI2/T EPS=0.01  ESTABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX  GO TO (1,2.3) INDEX  GO TO (1,2.3) INDEX  TNDEX=1, READ DATA FROM FILE 8 FOR PREVIOUS RUN OF MODEL  OOO1  *(ETA(I,J),J=1,N2),I=1,M),((V(I,J),J=1,N2),I=1,M),  *((U(I,J),J=1,N2),I=1,M),((V(I,J),J=1,N2),I=1,M),  *((W(I,J),J=1,N2),I=1,M),((Y(I,J),J=1,N2),I=1,M),  *((W(I,J),J=1,N2),I=1,M),((Y(I,J),J=1,N2),I=1,M),  *((W(I,J),J=1,N2),I=1,M),((Y(I,J),J=1,N2),I=1,M),  *((W(I,J),J=1,N2),I=1,M),((Y(I,J),J=1,N2),I=1,M),	UX2=UX*2.		0001166
ESTABLISH BOTTOM TOPOGRAPHY BASED ON VALUE OF INDEX  GO TO (1,2,3) INDEX  GO TO (1,2,3) INDEX  GO TO (1,2,3) INDEX  TNDEX=1, READ DATA FROM FILE 8 FOR PREVIOUS RUN OF MODEL  OCCUPATION (COLUMN) (COLUMN	STCMA=D10/T		0001168
GO TO (1.2.3) INDEX GO TO (1.2.3) INDEX INDEX=1, READ DATA FROM FILE 8 FOR PREVIOUS RUN OF MODEL  *(ETA(1.4), U=1.N2).I=1,M), ((D(I.U), U=1.N2).I=1,M),  *(U(I.U), U=1.N2).I=1,M), ((V(I.U), U=1.N2).I=1,M),  *(Z(I.U), U=1.N2), I=1,M), ((Y(I.U), U=1.N2).I=1,M),  *(X(I.U), U=1.N2), I=1,M), ((Y(I.U), U=1.N2), I=1,M),			0001169
GO TO (1,2,3) INDEX  INDEX=1, READ DATA FROM FILE 8 FOR PREVIOUS RUN OF MODEL  * (EAD(8,143)  * ((U(1,J),U=1,N2),I=1,M),(((D(1,U),U=1,N2),I=1,M),  * ((U(1,U),U=1,N2),I=1,M),((((1,U),U=1,N2),I=1,M),  * (X(1,U),U=1,N2),I=1,M),((((1,U),U=1,N2),I=1,M),  * ((M(1,U),U=1,N2),I=1,M),(((((,U),U=1,N2),I=1,M),	!	- P	0001170
INDEX=1, READ DATA FROM FILE 8 FOR PREVIOUS RUN OF MODEL  * (EAD(8,143)  * ((L(I,U),U=1,N2),I=1,M),((V(I,U),U=1,N2),I=1,M),  * ((L(I,U),U=1,N2),I=1,M),((Y(I,U),U=1,N2),I=1,M),  * ((M(I,U),U=1,N2),I=1,M),((Y(I,U),U=1,N2),I=1,M),  * ((M(I,U),U=1,N2),I=1,M),((Y(I,U),U=1,N2),I=1,M),	!		0001172
INDEX=1, READ DATA FROM FILE 8 FOR PREVIOUS RUN OF MODEL  * (EAD(8,113)  * ((III, U), U=1, N2), I=1, M), (((I, U), U=1, N2), I=1, M),  * ((II, U), U=1, N2), I=1, M), ((((I, U), U=1, N2), I=1, M),  * ((((I, U), U=1, N2), I=1, M), (((((I, U), U=1, N2), I=1, M),  * (((((I, U), U=1, N2), I=1, M), (((((((U, U), U=1, N2), I=1, M), U=1, N2), I=1, M),  * (((((((((((U, U), U=1, N2), I=1, M), U=1, N2), I=1, M), U=1, N2), I=1, M),			000
*(ETA[1,J),J=1,N2),I=1,M),((D[1,J),J=1,N2),I=1,M), *((U(1,J),J=1,N2),I=1,M),((V(I,J),J=1,N2),I=1,M), *((Z(I,J),J=1,N2),I=1,M),((H(I,J),J=1,N2),I=1,M), *((X(I,J),J=1,N2),I=1,M),((Y(I,J),J=1,N2),I=1,M),		8 FOR PREVIOUS RUN OF	0001175
	_	(2).I=1,M).((D(I.U).U=1.N2).I=1,M). .I=1,M).((V(I.U).U=1.N2).I=1,M). .I=1,M).((H(I.U).U=1.N2).I=1,M). .I=1,M).((Y(I.U).U=1.N2).I=1,M).	0001178 0001178 0001179 0001180 0001181

000 11830 000 11840 000 11880 000 11880 000 11890 000 11910 000 11910
READ(B. 107) ITD  DD 10 1-1, M  SILI, J-5082(21, J))  SILI, J-5082(21, J)  SILI, J-5082(21, J)  SILI, J-5082(21, J)  SILI, J-5082(21, J)  LETA GE 180.) GO TO 42  MANAG-PI2-WINANG  DD 10 24  MANAG-PI2-WINANG  DD 10 24  MANAG-PI2-WINANG  DD 10 24  MANAG-PI2-WINANG  DD 11 1, M
11860 118830 118840 118850 118860 118860 119

12450 1 12460 9	15 CONTINUE 95 IWET=1 IDRY="WET-1	00012450
	MAIN PROGRAM LOOP FOR EACH ITERATION	00012480
12500 12510 12520 12530	DO 4 IT=(1+ITD), ITA L=AMOD(FLOAT(IT), FLOAT(KSKIP)) HO=HEIGHT*TANH(FLOAT(IT)/(FLOAT(NHIGHT)/2.0))	00012500 00012510 00012520 00012530
	GO TO 13 CALL DGRAD CALL REFRAC(A. HO. IT. INDEX.NHIGHT. CF)	00012550
	TAUSB(WIND, WINANG, CF, ITD) UCALC ETAS	00012580 00012590 00012600
12610	SUM=0.0 D0 86 1=1,M	00012610
12630 12640 12650 12660 8	DU 86 U=2.N SUM=SUM=5(W(I,U)**2+Y(I,U)**2)*D(I,U-1) SUM=SUM+G*ETA(I,U)*(D(I,U-1)-O.5*ETA(I,U)) 86 CONTINUE	00012630 00012640 00012650 00012660
	WRITE SUM AFTER EACH ITERATION	00012670
	WRITE(6,100) SUM IF(L.NE.O)GD TO 4	00012690 00012700 00012710
12720 C* 12730 C* 12740 C*	WRITE WAVE HEIGHT, WAVE ANGLE, VELOCITIES, AND SETUP AT KSKIP INTERVALS	00012720 00012730 00012740
12750 C* 12760 12770	WRITE(6,109) WRITE(6,109)	00012750
12780	WRITE(6,112) WRITE(6,112)	00012780
12800 12810	1TE (6	00012800
12820 12830 401	DO 401 J=1.N1 22(I,J)=360.O-2(I,J)*RAD	00012820
12840 12850	WKITE(6,118) WRITE(6,103)(ZZ(I.U),U=1,N1),I=1,M)	00012840
12870	999	00012870
12890 12890	WRITE (6,103) ((V(I,J), J = 1,N1),I=1,M) WDITE (6,106)	00012890
12910 12920 4		00012910
12930 C* 12940 C*	WRITE THE RESULTS OF THE LAST ITERATION INTO AN OUTPUT FILE	00012930
		00012960
12980	* (ETA(1,0),(-1,N2),(-1,N2),((O(1,0),(-1,N2),(	00012970
13000	((Z(1, T), (Z(1, T), T), T), (Z(1, T), T), (	00013000
13020	* (TECL ) (2.1) (T.1) (T	00013020
	LOCK 3	00013040
		00013060

103 FORMAT (17.17) 104 FORMAT (17.17) 105 FORMAT (17.17) 106 FORMAT (17.17) 107 FORMAT (17.17) 108 FORMAT (17.17) 109 FORMAT (17.17) 109 FORMAT (17.17) 101 FORMAT (17.17) 101 FORMAT (17.17) 101 FORMAT (17.17) 102 FORMAT (17.17) 103 FORMAT (17.17) 104 FORMAT (17.17) 105 FORMAT (17.17) 107 FORMAT (1	3070		00013070
105   PORMAIT (1007.1977)   VELICITY (105   PORMAIT (1007.1977)   VELICITY (105   PORMAIT (1007.1977)   VELICITY (105   PORMAIT (105 Y. OHFTA VALUES)     105   PORMAIT (105 Y. IOHETA VALUES)     105	080	FORMAI (1X, 11F 10.4)	
107 FORMAT(15) 108 FORMAT(15) 109 FORMAT(15) 109 FORMAT(15) 109 FORMAT(15) 109 FORMAT(17) 101 FORMAT(17) 101 FORMAT(17) 101 FORMAT(17) 102 FORMAT(17) 103 FORMAT(17) 103 FORMAT(17) 104 FORMAT(17) 105 FORMAT(17) 105 FORMAT(17) 107 FO	200	FORMAT ( 10X 12HY -	00013100
100 FORMAT (//* THE AUGMENTED MATRIX DE WATER DEPTH IN WETERS'/) 109 FORMAT (//* THE AUGMENTED MATRIX DE WATER DEPTH IN WETERS'/) 109 FORMAT (10,* THE AUGMENTED MATRIX DE WATER DEPTH IN WETERS'/) 109 FORMAT (10,* THE AUGMENTED MATRIX DE WATER DEPTH IN MATRIX DE WATER DEPTH IN THE PORMAT (11,* "WATER HEIGHT S', "YO S ", "IS "ORMAT (11,* "WATER HEIGHT S', "YO S ", "IS ") 115 FORMAT (10,* "WATER HEIGHT SIDE" S', FT, 2." HEIGHT S', "YO S ", "IS ") 116 FORMAT (10,* "WATER HEIGHT SIDE" S', FT, 2." HEIGHT S', "YO S ",	3110	FDRMAT (10X, 10HETA	00013110
119 FORMAT (1/* THE ALUGRENTED MATRIX OF MATRE DEPTH IN WETERS')) 109 FORMAT (1/* THE ALUGRENTED MATRIX OF MATRE DEPTH IN WETERS')) 119 FORMAT (1/* "MAYE HEIGHTS".)) 119 FORMAT (1/* "MAYE HEIGHT BUILDS UP FIRST".) ITERATIONS") 119 FORMAT (1/* "MAYE HEIGHT BUILDS UP FIRST".) ITERATIONS") 119 FORMAT (1/* "MAYE HEIGHT BUILDS UP FIRST".) ITERATIONS") 119 FORMAT (1/* "MAYE HEIGHT BUILDS UP FIRST".) INAUGES REE"/ 120 FORMAT (1/* "MAYE HEIGHT BUILDS UP FIRST".) INAUGES REE"/ 121 FORMAT (1/* "MAYE HEIGHT BUILDS UP FIRST".) INAUGES REE"/ 122 FORMAT (1/* "MAYE HEIGHT BUILDS UP FIRST".) INAUGES REE"/ 123 FORMAT (1/* "MAYE FIRST".) INAUGES REES AND "MAYE HEIGHT CONCOUNTS", CALL "AND "MAYE REFRAC (THETAD. "HH. ITER. INDEX. "MHIGHT. CONCOUNTS") (2/* "PI "DEPTH GRID DO SMALL". LAST I. "J "MALUES RRE"/ 120 FORMAT (1/* "MAYE (1/* "M	3120	FORMAT (	00013120
110 FORMAT (10x, TIERATION NUMBER . 16, 10x, WAVE HEIGHT* . F10.5./) 111 FORMAT (10x, TIERATION NUMBER . 16, 10x, WAVE HEIGHT* . F10.5./) 112 FORMAT (15x, WAVE HEIGHTS .) 113 FORMAT (15x, WAVE HEIGHTS .) 114 FORMAT (15x, WAVE HEIGHTS .) 115 FORMAT (15x, WAVE HEIGHTS .) 116 FORMAT (15x, WAVE HEIGHTS .) 117 FORMAT (10x, WAVE HEIGHT BUILDS UP FIRST, 13x, TIERATIONS.) 118 FORMAT (10x, WAVE HEIGHT BUILDS UP FIRST, 13x, TIERATIONS.) 119 FORMAT (10x, WAVE HEIGHT BUILDS UP FIRST, 13x, TIERATIONS.) 119 FORMAT (10x, WAVE HEIGHT BUILDS UP FIRST, 13x, TIERATIONS.) 119 FORMAT (10x, WAVE MEIGHT BUILDS UP FIRST, 13x, TIERATIONS.) 119 FORMAT (10x, WAVE MEIGHT BUILDS UP FIRST, 13x, TIERATIONS.) 119 FORMAT (10x, WAVE MEIGHT BUILDS UP FIRST, 13x, TIERATIONS.) 119 FORMAT (10x, WAVE MEIGHT BUILDS UP FIRST, 13x, TIERATIONS.) 119 FORMAT (10x, WAVE MEIGHT BUILDS UP FIRST, 13x, TIERATIONS.) 110 FORMAT (10x, WAVE MEIGHT BUILDS UP FIRST, 13x, TIERATIONS.) 111 FORMAT (10x, WAVE MEIGHT BUILDS UP FIRST, 13x, TIERATIONS.) 112 FORMAT (10x, WAVE MEIGHT BUILDS UP FIRST, 13x, TIERATIONS.) 113 FORMAT (10x, WAVE MEIGHT BUILDS UP FIRST, 13x, TIERATIONS.) 114 FORMAT (10x, WAVE WEIGHT BUILDS UP FIRST, 13x, TIERATIONS.) 115 FORMAT (10x, WAVE WEIGHT BUILDS UP FIRST, 13x, TIERATIONS.) 116 FORMAT (10x, WAVE WEIGHT BUILDS UP FIRST, 13x, TIERATIONS.) 117 FORMAT (10x, WAVE WEIGHT BUILDS UP FIRST, 13x, TIERAT WAVE	3130	FORMAT (//' THE AUGMENTED MATRIX OF WATER DEPTH IN	00013130
111 FORMAT (10X, TTERATION NUMBER '. 16 (0X, WARE HEIGHT=', F10.5, f) 00001 111 FORMAT (10X, TTERATION NUMBER '. 16 (0X, WARE HEIGHT=', F10.5, f) 0001 112 FORMAT (10X, WAVE HEIGHTS', f) 0001 113 FORMAT (10X, WAVE HEIGHTS', f) 0001 114 FORMAT (10X, WAVE HEIGHT BULIDS UP F183'; 13, TTERATIONS') 0001 115 FORMAT (10X, WAVE HEIGHT BULIDS UP F183'; 13, TTERATIONS') 0001 116 FORMAT (10X, WAVE HEIGHT BULIDS UP F183'; 13, TTERATIONS') 0001 117 FORMAT (10X, WAVE HEIGHT BULIDS UP F183'; 13, TTERATIONS') 0001 118 FORMAT (10X, WAVE PREMEERES), FORMAT (10X, WAVE PREMEERES) 0001 119 FORMAT (10X, WAVE PREMEERES), FORMAT (10X, WAVE PREMEERES) 0001 119 FORMAT (10X, WAVE PREMEERES), FORMAT (10X, WAVE PREMEERES) 0001 119 FORMAT (10X, WAVE PREMEERES), FORMAT (10X, WAVE PREMEERES) 0001 119 FORMAT (10X, WAVE PREMEERES), FORMAT (10X, WAVE PREMEERES) 0001 119 FORMAT (10X, WAVE PREMEERES), FORMAT (10X, WAVE PREMEERES) 0001 119 FORMAT (10X, WAVE PREMEERES), FORMAT (10X, WAVE PREMEERES) 0001 119 FORMAT (10X, WAVE PREMEERES) 0001 110 FORMAT (10X, F) 10X, FORMAT (10X, WAVE PREMEERES) 0001 111 FORMAT (10X, WAV	1140	( , , , , , , , , , , , , , , , , , , ,	000131
11 FORMAT (18.7 ************************************	150	FORMAT (10X, 'ITERATION NUMBER', 16, 10X, 'WAVE HEIGHT=', F10.5	000131
112 FORMAT (1558 4) 114 FORMAT (1558 4) 115 FORMAT (1558 4) 115 FORMAT (1558 4) 115 FORMAT (1558 4) 116 FORMAT (157 4) 117 FORMAT (157 4) 118 FORMAT (157 4) 119 FORMAT (157 4) 110 FORMAT (157 5) 110 FORM	160		000131
113 FORMAT (11X, WIND SPEED = 'F7.3.'M/SEC'.5X.'WIND ANGLE = 'F7.  114 FORMAT (11X, WIND SPEED = 'F7.3.'M/SEC'.5X.'WIND ANGLE = 'F7.  115 FORMATI (11X, WIND SPEED = 'F7.3.'M/SEC'.5X.'WIND ANGLE = 'F7.  116 FORMATI (11X, WAVE PRIGHT BUILDS UP FIRSY.'I3.' ITERATIONS')  118 FORMATI (11X, WAVE PRIGHT BUILDS UP FIRSY.'I3.' ITERATIONS')  119 FORMATI (11X, WAVE PRIGHT BUILDS UP FIRSY.' I3.' ITERATIONS')  119 FORMATI (11X, WAVE PRAMMETERS', ZAX, 12HEACH SLOPE., F7.2.'  12 X. TANAGLE = 'F7.2.' IX, THOEGREES, AX, 12HEACH SLOPE., F7.4')  12 X. I2 ZX.' I2)  12 FORMATI (11X, WAVE PRAMMETERS', ZAX, 12HEACH SLOPE., F7.4')  13 FORMATI (11X, WAVE PRAMMETERS', ZAX, 12HEACH SLOPE., F7.4')  14 FORMATI (11X, WAVE PRAMMETERS', ZAX, 12HEACH SLOPE., F7.4')  15 FORMATI (11X, WAVE PRAMMETERS', ZAX, 12HEACH SLOPE., F7.4')  16 FORMATI (11X, WAVE PRAMMETERS', ZAX, 12HEACH SLOPE., F7.4')  17 FORMATI (11X, WAVE PRAMMETERS', ZAX, 12HEACH SLOPE., ZAX, ZAX, ZAX, ZAX, ZAX, ZAX, ZAX, ZAX	1170		000131
115 FORMATI (1), WIND SPEED 1: 17: 3: WIND SPEED 2: 17: 3: WIND SPEED 2: 17: 3: WIND SPEED 3: 3:	180	FORMAT(19F8.4)	000131
115 FORMAT (10X. INDEX * . I.B., 3X. '1D * . I.B.) 116 FORMAT (10X. WANC HETE = F.FO.3.) 117 FORMAT (10X. WANC HETE = F.FO.3.) 118 FORMAT (10X. WANC HETE = H.FO.3.) 119 FORMAT (10X. WANC HETE = H.FO.3.) 110 FORMAT (10X. WANC HETE = H.FO.3.) 110 FORMAT (10X. WANC HETE = H.FO.3.) 111 FORMAT (10X. WANC HETE = H.FO.3.) 111 FORMAT (10X. WANC HETE = H.FO.3.) 112 FORMAT (10X. WANC HETE = H.FO.3.) 113 FORMAT (10X. WANC HETE = H.FO.3.) 114 FORMAT (10X. WANC HETE = H.FO.3.) 115 FORMAT (10X. WANC HETE = H.FO.3.) 116 FORMAT (10X. WANC HETE = H.FO.3.) 117 FORMAT (10X. WANC HETE = H.FO.3.) 118 FORMAT (10X. WANC HETE = H.FO.3.) 119 FORMAT (10X. WANC HETE = H.FO.3.) 110 FORMAT (10X. WANC H.F. H.F. H.F. H.F. H.F. H.F. H.F. H.F	190	FORMAL (1X, WIND SPEED H', F7.3, M/SEC', 5X, WIND ANGLE	000
116 FORMATIONS (1974) 117 FORMATIONS (1974) 118 FORMATIONS (1974) 119 FORMATIONS (1974) 119 FORMATIONS (1974) 110 FORMATIONS (1974)	200		000132
117 FORMAT (10X, WAYE HEIGH BUILDS UP FIRST, 13, ITERATIONS) 118 FORMAT (10X, WAYE HEIGH BUILDS UP FIRST, 13, ITERATIONS) 119 FORMAT (10X, WAYE MAGILE (DEGREES), AX, 12HERACH SLOPE=FT 4) 120 S.3X, 774ANGLE = FT 2. 1X, 74DEGREES, AX, 12HERACH SLOPE=FT 4) 120 FORMAT (1. 1RA) I DEPTH GRID TOD SMALL. LAST I.J VALUES ARE"/ 120 X 12 X, 12) 120 ST 12 ZX, 12) 120 CC 121 ZX, 12 ZX, 12) 120 FORMAT (1. 1RA) I DEPTH GRID TOD SMALL. LAST I.J VALUES ARE"/ 120 FORMAT (1. 1RA) I DEPTH GRID TOD SMALL. LAST I.J VALUES ARE"/ 120 ST 12 ZX, 12 ZX, 13 120 CC 120 C	200		25.000
118 FORMATION: WAVE FELCH DILLSS UP TIEST 1.3: THERATIONS ) 119 FORMATION: WAVE PRANMETERS //2X. FRENDD = / F7 2, THEIGHT = / F7 120 FORMATION: WAVE PRANMETERS //2X. FRENDD = / F7 2, THEIGHT = / F7 120 FORMATICE = / F7 2, IX, THEIGHTS //2X. FRENDD = / F7 2, THEIGHT = / F7 120 FORMATICE = / F7 2, IX, THEIGHTS //2X. FRENDD = / F7 2, THEIGHT = / F7 120 FORMATICE = / F7 2, IX, THEIGHTS //2X. FRENDD = / F7 2, THEIGHT = / F7 120 FORMATICE = / F7 2, IX, THEIGHT = / F7 120 FORMATICE = / F7 2, IX, THEIGHT = / F7 120 FORMATICE = / F7 2, IX, THEIGHT = / F7 120 FOR EACH ITERATION 121 FORD FOR EACH ITERATION 121 FORD FOR EACH ITERATION 122 FOR EACH ITERATION 123 FORD FOR EACH ITERATION 124 FOR EACH ITERATION 125 FOR EACH ITERATION 126 FOR EACH ITERATION 127 FOR EACH ITERATION 128 FOR EACH ITERATION 127 FOR	0770	FURMA! (10%,4MCF = ,F10.6,5%,4MUD = ,F10.6)	25.000
119 FORMAT(1X.* WAVE PARAMETERS.*/ S.Y. "PERIOD =', F7.2', HEIGHT =', F7 - 2', 3', THANGLE =', F7.4'   120 FORMAT(1X.* WAVE PARAMETERS.*/ S.Y. "PERIOD =', F7.2', HANGLE ARE"/ 121 FORMAT(1X.* WAVE PARAMETERS.*/ S.Y. "PERIOD =', F7.2', HANGLE ARE"/ 122 FORMAT(1X.* WAVE PARAMETERS.*/ S.Y. "PERIOD =', F7.2', HANGLE ARE"/ 123 FORMAT(1X.* WAVE PARAMETERS.*/ S.Y. "PERIOD =', F7.2', HANGLE ARE"/ 124 FORMAT(1X.* WAVE PARAMETERS.*/ S.Y. "PERIOD =', F7.2', HEIGHT 125 FORMAT(1X.* WAVE PARAMETERS.*/ S.Y. "PERIOD =', F7.2', F7.4') 127 FORMAT(1X.* WAVE PARAMETERS.*/ S.Y. "PERIOD =', F7.2', F7.4') 128 FEAC CONTROLS THE CALCULATION OF WAVE ANGLE AND WAVE HEIGHT 129 FORMATON OF SO. SO. (150.50), (150.50), 18(80.5	0570	117 FORMER (100) "KANE MELGET BOLLEUN OF TIRUT. 16, ILERALIONS OF TAX POLICY OF	25.000
130 FORWART 13. WAY PARAMETERS 7. (Z.). FOR FILENT 1. J. VALUES ARE 7. (Z.). THANGE E. F. 7. Z.). THANGE E. F. 7. Z.	041	TOTAL (Z.), WAVE ANGLE (DEGREES).)	2000
120 FORMATI ** INPUT DEPTH GRID TOD SWALL** LAST 1.J VALUES ARE*/ 121 22.12  STOP  END  C** SUBROUTINE REFRAC(THETAQ.HH, ITER.INDEX.NHIGHT.CF)  C** COMMON DISO.** C** C** C** C** C** C** C** C** C**	250	TORBELLING. TAKE MAKEMETEKN. '/AX, TREKIOD ". "T.'X."  TORBELLING. T. TELLING. T. TELLING. T. TELLING.	25.000
12X, 122, 2X, 12)  EVENTION OF THE CALCULATION OF WAVE ANGLE AND WAVE HEIGHT  C. SUBROUTINE REFRAC(THETAO, HH, ITER, INDEX, NHIGHT, CF)  C. REFRAC CONTROLS THE CALCULATION OF WAVE ANGLE AND WAVE HEIGHT  C. FOR EACH ITERATION  FIRE FOR EACH ITERATION	020		25.000
Common   C	0770		25.000
SUBROUTINE REFRAC(THETAO, HH, ITER, INDEX, NHIGHT, CF)  C** SUBROUTINE REFRAC(THETAO, HH, ITER, INDEX, NHIGHT, CF)  C** REFRAC CONTROLS THE CALCULATION OF WAVE ANGLE AND WAVE HEIGHT  C** COMMON DEGO SO), UEGO, SO), 2(50, 50), 2(150, 5	280	ZX, IZ, ZX, IZ)	860132
C. SUBRDUTINE REFRAC(THETAO, HH, ITER, INDEX, NHIGHT, CF)  C. REFRAC CONTROLS THE CALCULATION OF WAVE ANGLE AND WAVE HEIGHT  C. COMMON OF 100.500 JU(50,500). X(50,500). X(50,50	062	10 - 0 H	000
C. SUBROUTINE REFRAC(THETAO, HH, ITER, INDEX, NHIGHT, CF)  C. REFRAC CONTROLS THE CALCULATION OF WAVE ANGLE AND WAVE HEIGHT  C. FOR EACH ITERATION  C. COMMON DISO. 50). U(50, 50). X(50, 50). X(50, 50). X(50, 50).  COMMON STRESS/SIGKT50. 50). X(50, 50). X(50, 50). X(50, 50). X(50, 50).  **H(50, 50). CG(50, 50). X(50, 50). X(50, 50). X(50, 50). X(50, 50).  **H(50, 50). CG(50, 50). X(50, 50). X(50, 50). X(50, 50). X(50, 50).  COMMON/STRESS/SIGKT50. 50). X(50, 50). X(50, 50). X(50, 50).  **H(50, 50). TAUSX (50, 50). TAUSX (50, 50). X(50, 50).  COMMON/STRESS/SIGKT50. 50). TAUSX (50, 50). X(50, 50).  **M.N.N. N. M. N. N. M.		1	000
SUBROUTINE REFRAC(THETAO.HH,ITER,INDEX,NHIGHT,CF)  C. REFRAC CONTROLS THE CALCULATION OF WAVE ANGLE AND WAVE HEIGHT  C. FOR EACH ITERATION  C. COMMON D(SO, 50), U(50, 50), Z(50, 50), SIGN(50, 50),  C. COMMON D(SO, 50), TAUSN(50, 50), SIGN(50, 50), IRUSN(50, 50),  C. COMMON/CONST/ G, PI, PI2, RAD, FPS, DV, DV, DV, DV, DV, DV, DV, DV, DV, DV		,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	000133
Common D(SO, SO), U(SO, SO), 2(SO, SO), 2(SO			000133
C* REFRAC CONTROLS THE CALCULATION OF WAVE ANGLE AND WAVE HEIGHT C* COMMON D(50.50). U(50.50). V(50.50). Z(50.50). Z(50.50). CONTROLS C* COMMON D(50.50). U(50.50). V(50.50). Z(50.50). Z(50.50). DDDX(50.50). CONTROLS C* COMMON D(50.50). U(50.50). V(50.50). Z(50.50).			000133
Common D(50.50).U(50.50).Y(50.50).S(50.50).DDX(50.50).  COMMON D(50.50).U(50.50).Y(50.50).S(50.50).B(50.50).DDX(50.50).  *H(50.50).CG(50.50).S(50.50).HBREAK(50.50).B(50.50).DDX(50.50).  *H(50.50).TAUSX(50.50).TAUSX(50.50).TAUSX(50.50).TAUSX(50.50).  *COMMON/STRESS/SIGX(50.50).TAUSX(50.50).TAUSX(50.50).TAUSX(50.50).  *COMMON/STRESS/SIGX(50.50).TAUSX(50.50).TAUSX(50.50).  *M.N.N. N.Z. M. M.Z. M. DD. TT. RND. LWT. JDRY. JD.  IF (ITER GT (NHIGHT)) GD TD GOO  *COMMON/CONST (* P. PIZ. PRD. EPS. DX. DY. DT. DX. DY. Z. T. SIGMA.  *M.N. N. N. N. M. M. M. M. D. M. D. T. RND. JWT. JDRY. JD.  *M. N. N. N. N. N. N. M. M. D. M. D. T. RND. JWT. JWT. JDRY. JD.  *M. N. N. N. N. N. N. M. D. J. P. M. D. J. M. D. D. J. M. M. J. M. D. J. J. M. M.			000
COMMON D(SO, 50), U(SO, 50), V(SO, 50), Z(SO, 50), SI(SO, 50), CO(SO, 50), *H(SO, 50), CO(SO, 50), TAUBX(50, 50), TAUBX(50, 50), TAUBX(50, 50), TAUBX(50, 50), TAUBX(50, 50), TAUSX(50, 50),			000
Common Viscos (10, 10, 10, 10, 10, 10, 10, 10, 10, 10,		2	
COMMON D(50.50).U(50.50).V(50.50).S(50.50).C(50.50). **H50.50).CG(50.50).S(50.50).HBREAK(50.50).IB(50.50).DDDX(50.50). **H50.50).CG(50.50).S(50.50).HBREAK(50.50).IB(50.50).DDDX(50.50). COMMON/STRESS/SIGX(50.50).SIGY(50.50).SIGXY(50.50).TAUBX(50.50).  **TAUBY(50.50).TAUGX(50.50).TAUGY(50.50).SIGXY(50.50).TAUBX(50.50).  **M.N.N.1.NZ.M.1M2.AM.DD.1.P.RDL.EPS.DX.DY.DT.DX2.DY2.T.SIGMA.  **M.N.N.1.NZ.M.1M2.AM.DD.1.P.RDL.EPS.DX.DY.DT.DX2.DY2.T.SIGMA.  **M.N.N.1.NZ.M.1M2.AM.DD.1.P.RDL.EPS.DX.DY.DY.DY2.DY2.T.SIGMA.  CALL SNELL CHETGHT BUTG BUILDUP OF DEEP WATER WAVE  CALL SNELL CHETAPL ADD.  CALL HETGHT (25.CF)  CALL HETGHT (25.CF)  CALCULATE THE RADIATION STRESSES  CALCULATE THE RADIATION STRESSES  C*****CALCULATE THE RADIATION STRESSES  C*****CALCULATE THE RADIATION STRESSES  C********************************			000
*H(50,50), CG(50,50), S(50,50), HBREAK(50,50), DDDX(50,50)  *DDDY(50,50), CG(50,50), S(50,50), HBREAK(50,50), DDDX(50,50),  *DDDY(50,50), TAUSX(50,50), SIGXY(50,50), TAUBX(50,50),  *TAUBY(50,50), TAUSX(50,50), TAUSX(50,50), TAUBX(50,50),  **MININIA, MININIA, MININ			
*, DDDY(50, SO) *, DDDY(50, SO) *, DDDY(50, SO) *, DDDY(50, SO) *, TAUSX(50, SO), SIGY(50, SO), SIGXY(50, SO), TAUBX(50, SO) *, TAUBY(50, SO), TAUGX(50, SO)  ***A**, N. N. 1, N. 2, M. 1, M. 2, M. 2, M. 3, M. 1, M.	06.6		000133
COMMON/STRESS/SIGX(50,50), SIGX(50,50), TAUBX(50,50), *TAUBX(50,50), TAUSX(50,50), TAUSX(50,50) COMMON/CONST/ G.PI.PI2.RaD.PS.DX.DY.DT.DX2,DY2,T.SIGMA, *M.NI,NZ.MI,NZ.AM.DD.JT.RHO.JWET,IDRY,ID  IF (ITER.GT.(NHIGHT)) GO TO GOO  C***CALL SNELL DURING BUILDUP OF DEEP WATER WAVE  CALL SNELL (THETA,HH,ITER)  GOO DO SO I=1,IDRY  DO SO J=1,IDRY  DO SO J=1,IDRY  CALL MALE(25)  CALL HIGHT(25,CF)  CALL HIGHT(25,CF)  C***CALCULATE THE RADIATION STRESSES  C****CALCULATE THE RADIATION STRESSES  C***CALCULATE THE RADIATION STRESSES  C***CALCULATE THE RADIATION STRESSES  C****CALCULATE THE RADIATION STRESSES  C*****CALCULATE THE RADIATION STRESSES  C****CALCULATE THE RADIATION STRESSES  C****CALCULATE THE RADIATION STRESSES  C****CALCULATE	4 10	* DDDY (50-50)	000134
*TAUBY(50,50),TAUSX(50,50),TAUSX(50,50)  *TAUBY(50,50),TAUSX(50,50),TAUSX(50,50)  *M.N.NI.NZ.MI.MZ.AM.DD.IT.RAD.IEPS.DX.DY.DT.DXZ.DYZ.T.SIGMA,  *M.N.NI.NZ.MI.MZ.AM.DD.IT.RAD.IEPS.DX.DY.T.DZ  IF (ITER GT (NHIGHT)) GO TO 600  CALL SNELL CHETAO/RAD  CALL SNELL (THETA-HH.ITER)  600 DG 50 I=1,IDRY  DO 50 J=1,NZ  H(I,J)=0.0  Z(I,J)=PI  SI(I,J)=0.0  CO(I,J)=1.0  SO CONTINUE  CALL HGIGHT(25,CF)  C**CALCULATE THE RADIATION STRESSES  C**CALCULATE THE RADIATION	1420	COMMON/STRESS/SIGX(50.50).SIGY(50.50).SIGXY(50.50).TAUBX(50.50).	000134
COMMON/CONST/ G.PI.PI2.RAD.EPS.DX.DY,DT.DX2,T.SIGMA,  *M.N.1,N2,M1,M2,AM.DD.IT.RHO,IWET,IDRY,ID  IF (ITER.GT (NHIGHT)) GO TO 600  C* CALL SNELL DURING BUILDUP OF DEEP WATER WAVE  C* CALL SNELL (THETA,HH,ITER)  600 DO 50 I=1,IDRY  DO 50 J=1,N2  HIT,J=0.0  Z(I,J)=PI  S1(I,J)=0.0  CO(I,J)=-1.0  SO CONTINUE  CALL ANGLE(25)  C* CALCULATE THE RADIATION STRESSES  C* CALCULATE THE PIDATION ST	1430	*TAUBY(50,50),TAUSX(50,50),TAUSY(50,50)	000134
*M.N.N1,N2,M1,M2,MM,DD,IT,RHD,IWET,IDRY,ID  IF (ITER.GT.(NHIGHT)) GO TO 600  C* CALL SNELL DURING BUILDUP OF DEEP WATER WAVE  CALL SNELL (THETA-HH,ITER)  600 DO 50 I=1,IDRY  DO 50 J=1,N2  H(1,J)=0.0  C(1,J)=1.0  S1(1,J)=1.0  S0(1,J)=1.0  S0(1,J)=1.0  CALL ANGLE(25)  CALL HIGHT(25,CF)  C* CALCULATE THE RADIATION STRESSES  C* CALCULATE THE RADIATION STRESSES  C* CALCULATE THE NADIATION STRESSES	440	COMMON/CONST/ G.PI.PI2.RAD, EPS.DX.DY.DT.DX2,DY2,T.SIGMA,	000134
The control of control	1450	*M.N.N1, N2, M1, M2, AM.DD, IT, RHO, IWET, IDRY, ID	000134
C***CALL SNELL DURING BUILDUP OF DEEP WATER WAVE  THETA=P12-THETAO/RAD  CALL SNELL (THETA, HH, ITER)  600 D0 50 1=1, IDRY  D0 50 0=1, N2  H(I, J)=0.0  Z(I, J)=1.0  SO CONTINUE  CALL ANGLE(25)  C***CALCATE THE RADIATION STRESSES  C***CALCATE THE R			000134
C* CALL SNELL DURING BUILDUP OF DEEP WATER WAVE  CALL SNELL (THETA, HH, ITER)  600 D0 S0 I= 1, IDRY  D0 S0 0= 1, N2  H(I, J) = 0.0  Z(I, J) = PI  SI(I, J) = 1.0  S0 CONTINUE  CALL ANGLE(25)  C* CALCULATE THE RADIATION STRESSES  C* CA			000134
CALL SNELL (THETA, HH, ITER)  600 DD 50 I=1, IDRY  DD 50 O=1, N2  H(I, J)=0.0  Z(I, J)=1.0  SO (SOUTH NULLE CALL NULLE (CALL ANGLE (25))  CALL HEIGHT (25, CF)  CALL HEIGHT (25, CF)  CALCULATE THE RADIATION STRESSES  C**  C**  C**  C**  C**  C**  C**		CALL	000134
GOO DO SO I = 1,1DRY  GOO DO SO I = 1,1DRY  DO SO J = 1,0O  COLI, J) = 0.0  COLI, J) = -1.0  SO CONTINUE  CALL ANGLE(25)  CALL HEIGHT(25,CF)  C**  COLCULATE THE RADIATION STRESSES  C**  C**  C**  C**  C**  C**  C**		CATTLE CTO-ATTLE	2000
600 DD 50 I = 1, IDRY DD 50 J = 1, N2 H(I,J) = 0.0 Z(I,J) = PI SI(I,J) = 0.0 COLI,J) = -1.0 SO CONTINUE CALL ANGLE(25) C***CALCUATE THE RADIATION STRESSES C****CALCULATE THE RADIATION STRESSES C****CALCULATE THE RADIATION STRESSES C*****CALCULATE THE RADIATION STRESSES C******CALCULATE THE RADIATION STRESSES C*****CALCULATE THE RADIATION STRESSES C*******CALCULATE THE RADIATION STRESSES C*****CALCULATE THE RADIATION STRESSES C**********CALCULATE THE RADIATION STRESSES C*****CALCULATE THE RADIATION STRESSES C*********************************	200	HELMEYIZ-HELMOVIKAD	000
Coll. (1) = PI SI(I, J) = PI SI(I, J) = PI SI(I, J) = PI SI(I, J) = PI SO CONTINUE CALL ANGLE(25) C************************************	0.00		2000
H(I, J) = 0.0  Z(I, J) = PI  SI(I, J) = 0.0  CO(I, J) = -1.0  SO CONTINUE  CALL ANGLE(25)  C* CALCUATE THE RADIATION STRESSES  C* CALCUATE THE RADIATION STRESSES  C* DO 57 I=IWET.M1  DO 21 J=3.N1  ENERGY=0.125*RHOTG=(H(I, J)**2)  SIGX(I, J) = SIGX(I, J) * ENERGY  SIGX(I, J) = SIGX(I, J) * ENERGY	55.00		000
Z(I, J) = PI SI(I, J) = PI SI(I, J) = O. O CO(I, J) = 1.O SO CONTINUE CALL ANGLE (25) CALL HEIGHT (25, CF) C* CALCULATE THE RADIATION STRESSES C**** DO 57 I=IWET, M1 DO 27 J=IWET, M1 DO 21 J=3.N1 ENERGY=O. 125*RHO*G*(H(I, J)**2) SIGX(I, J) = SIGX(I, J)	540	C CH(T) I)H	000135
SI(I, U) = 0.0 CO(I, U) = -1.0 SO CONTINUE CALL HEIGHT(25,CF) C****CALCULATE THE RADIATION STRESSES C****CALCULATE THE RADIATION STRESSES C*****CALCULATE THE RADIATION STRESSES C****CALCULATE THE RADIATION STRESSES STG**(I, U) = STG**(I, U) * * * * * * * * * * * * * * * * * *	550	1d=(7:1)2	000135
CO(I, J) = -1.0  SO CONTINUE CALL ANGLE(25) CALL HEIGHT(25, CF)  C** CALCULATE THE RADIATION STRESSES C** CALCULATE THE RA	1560	0.0=(7.1)18	000135
SO CONTINUE CALL ANGLE(25) CALL HEIGHT(25,CF) C***CALCULATE THE RADIATION STRESSES SIGN(I, J)**SIGN(I, J)**ENERGY CALCULATE THE RADIATION STRESSES C***CALCULATE THE RADIATION STRESSES C***CALCULAT	1570	C0(1,U)=-1.0	000135
CALL ANGLE(25)  CALL HEIGHT(25,CF)  C** CALCULATE THE RADIATION STRESSES  C** DO 57 I=IWET.M1  DO 21 J=3,N1  ENERGY=0.125*RHO+G+(H(I,J)++2)  SIGX(I,J)=SIGX(I,J)+ENERGY	580		000135
CALL HEIGHT (25, CF)  C* CALCULATE THE RADIATION STRESSES  C* DD 57 I=IWET.M1  DD 21 J=3,N1  ENERGY=0, 125*RHO+G=(H(I,J)++2)  SIGX(I,J)=SIGX(I,J)*ENERGY	9230	ANGLE (25)	000135
C* CALCULATE THE RADIATION STRESSES  C*		CALL HEIGHT (25	000136
C*************************************		CALCULATE THE DANIATION CIDENCE	92.00
DD 57 I=IWET.M1 DD 21 J=3,N1 ENERGY=0.155*RHO*G*(H(I.J)**2) SIGX(I.J)=SIGX(I.J)*ENERGY		1071416 1074 1474 1474 1474 1474 1474 1474 1474	000136
DD 21 J=3,N1 ENERGY=0.155*RHO*G*(H(I,J)**2) SIGX(I,J)=SIGX(I,J)*ENERGY <1GY(I,J)=SIGX(I,J)*ENERGY		00	00013640
ENERGY=0.125*RHO+G+(H(I,U)++2) SIGX(I,U)=SIGX(I,U)=ENERGY AIGY(I,I)=SIGX(I,I)+FENERGY	1650	DO 21 J=3,N1	000136
0.147(1.1.0) 0.147(1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.	900	ENERGY = 0.125 * RHO * G * (H(I, U) * * 2)	000136
	2/9	0.1GX[1,1,0]=0.1GX	900136

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S1GXY(1, J) = S1GXY(1, J) * ENERGY  21 CONTINUE	**H\$6.50, CG\$60,50, S\$60,50, HBREAK\$60,50), IB\$60,50), DDDX(\$60,50) **DDX(\$60,50), U\$60,50), U\$60,50,
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*H(50,50),CB(50,50),S(50,50),HBREAK(50,50),IB(50,50),DDDX(50,50)
*DDDY(50,50),U(50,50),V(50,50)
COMMON/CONST,G,PI,PI2,RAD,EPS,DX,DY,DI,DX2,DY2,T,SIGMA,
*M.N.N.1,N2,M1,M2,AM,DD,IT,RHG,IMET,IDRY,ID
COMMON/STRES/SIGK(50,50),SIGY(50,50),SIGXY(50,50),TAUBX(50,50),
*TAUBY(50,50),TAUSX(50,50),TAUSY(50,50)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    X=RKA(I, U)*CF*SIGMA*H(I, U)/(6.*PI*(CH**3.-CH))
X=X+G*PERM*RKA(I, U)/(VISCOS*CH*CH)
                                                                                                                                                                                              DCDX=Q*(RK*SECHSQ*DKDDX-TA*DKDX(I,J))
DCGY*Q*(RK*SECHSQ*DKDDY-TA*DKDY(I,J))
DCGDX=P*DKDDX+FF*DCDX
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  SIGXX*(2.0*FF-0.5)*CC2+(FF-0.5)*SS2
SIGYY*(2.0*FF-0.5)*SS2+(FF-0.5)*CC2
                                                                                                                                  CG(I,J)=FF*C
P=C*(SINHS-ARG2*COSH2)/SINHSQ
DKDDX=RK*DDDX(I,JJ)+DEP*DKDX(I,J)
DKDDY=RK*DDDY(I,JJ)+DEP*DKDY(I,J)
0=0.5*G/(C*RK**2)
                                                                                                                                                                                                                                                                                                               HEIGHT CALCULATES THE WAVE HEIGHT
                                                                                                                                                                                                                                                                                                                                                                                                                                       VISCOS=1.0E-05

PERM=1.06E-09

DG 500 J=2.M1

DG 500 J=2.N1

IF(D(I, J-1).E.DD) GD TD 499

CALL GROUP(I, J, DCGDX, DCGDY, FF)

DUDX=(W(I+1, J)-W(I, J))/DX

DUDY=(V(I, J+1)-V(I-1, J))/DX

DVDY=(Y(I, J+1)-Y(I, J))/DX

DTDX=(Z(I+1, J)-Z(I-1, J))/DX2

DTDX=(Z(I+1, J)-Z(I-1, J))/DX2

DTDY=(Z(I+1, J)-Z(I-1, J))/DX2
(J.EQ.3) RKA(I,N2)=RKA(I,J)
                                                                                                                                                                                                                                                                                        SUBROUTINE HEIGHT (ITMAX.CF)
                  HBREAK(I,J)=0.12*P12*TA/RK
COSH1=COSH(RK*DEP)
SECHSQ=1.0/(COSH1**2)
ARGZ=2.0*RK*DEP
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       CH=COSH(RKA(1,J)*D(1,J-1))
IF(ID.EQ.1) GD TD 301
                                                                                                   EE=E(1,J)
C=SQRT(G*TA/RK)
FF=O.5*(1.0+ARG2/SINH2)
                                                                                                                                                                                                                                DCGDY = P * DKDDY + F F * DCDY
                                                                 SINH2=SINH(ARG2)
COSH2=COSH(ARG2)
SINHSQ=SINH2**2
        TA = TANH ( RK + DEP )
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  SS2=SI(I,J)**2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             CC2=CO(I,J)**2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          GO TO 302
                                                                                                                                                                                                                                             RETURN
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SIGX(I.J) = SIGXX

SIGY(I.J) = SIGYY

TAUXY=FFSI(I.J)*CO(I.J)

SIGXY(I.J)=TAUXY

S(I.J)*CG(I.J)*(SI(I.J)*DTDX-CO(I.J)*DTDY)-(DUDX+DVDY)-(CO(I.J)*DC

*GDX+SI(I.J)*DCGDY)-(SIGXX*DUDX+TAUXY*DUDY+TAUXY*DVDX+SIGYY*DVDY)-X
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                540 FORMAT(' RELAXATION FOR THE WAVE HEIGHT FAILED TO CONVERGE', *'ON ROW ',15,'AFTER',16,'ITERATIONS')
WRITE(6,541)(H(1,J),J=1,N2 )
541 FORMAT(' LAST VALUES OF H ARE'/,10F13.5)
                                                                                                                                                                                                         CC2=(U(I,J)+CG(I,J)+CG(I,J)/DX

HNEW(I,J)= (CC1+H(I,J-1)-CC2+H(I+1,J))/(CC1-CC2-S(I,J)/2.0)

IF (HNEW(I,J) LT. O.O) GO TO 810

HT (HNEW(I,J)-LE.HBREAK(I,J)) GO TO 850

HNEW(I,J)=HBREAK(I,J)
                                                                                                                                                                                                                                                                                          IF(ABS(HNEW(I, U)-H(I, U)).GT.(EPS*ABS(HNEW(I, U)))) IFLAG"O
                                                                                                                                                                                    IB(I, J)=1
CC1=(V(I, J)+CG(I, J)*SI(I, J))/DY
                                                                                                                                                                        IF(D(I, J-1) LE. DD) GO TO 520
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                IF(IFLAG.EQ.1) GO TO 570
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             SUBROUTINE ANGLE (ITMAX)
                                                                                                                                                                                                                                                                                                                                                                               O IF(U.NE.3) GD TD 801
HNEW(I,N2)=HNEW(I,U)
IB(I,N2)=I8(I,U)
IIF(U.NE.N) GD TO 802
HNEW(I,I)=HNEW(I,U)
GD TD 520
                                                                                                                                                                                                                                                                                                                                    IF(J.NE.2) GO TO 800
HNEW(I,N1)=HNEW(I,J)
IB(I,N1)=IB(I,J)
GO TO 520
                                                                                                                                                                                                                                                                                                                                                                                                                                                                 IF(J.NE.N1) GD TD 520
                                                                                                                                                                                                                                                                                                                BOUNDARY CONDITIONS
                                                                                                                                                                                                                                                                                                                                                                                                                                                                           \mathsf{HNEW}(\mathtt{I},\mathtt{2}) = \mathsf{HNEW}(\mathtt{I},\mathtt{J})

\mathsf{IB}(\mathtt{I},\mathtt{2}) = \mathsf{IB}(\mathtt{I},\mathtt{J})
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    WRITE(6,540) 1,1TT
                                                                                                                                       DO 580 ITT=1, ITMAX
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       H(I, U) "HNEW(I, U)
                                                                                           SIGXY(I,J)=0.0
CONTINUE
                                                                                                                 DO 510 II=1,M2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              DO 625 J=1,N2
                                                                                                                                                              DD 520 J=2,N1
                                                                                H(I,J)=0.0
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    CONTINUE
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 DKDx(I,J)=(-(COSI*DUDx(I,J)+SINI*DVDx(I,J))-A*DDDx(I,J-1)/SINH2)/F
                                                                                                                                                                                                                                                                                                                                                                                                                                    C(I, J) = 0.25*(C0(I+1, J) + C0(I-1, J) + C0(I, J+1) + C0(I, J-1)) + 0.125*(Z(I+1, J) + J) + (Z(I, J+1) - Z(I, J-1)) + (Z(I, J+1) - Z(I, J+1) - Z(I, J+1)) + (Z(I, J+1) - Z(
                                                                                                                            COMMON D(50,50),W(50,50),Y(50,50),Z(50,50),SI(50,50),CO(50,50),
*H(50,50),CG(50,50),S(50,50),HBREAK(50,50),IB(50,50),DDDX(50,50),
*,DDDY(50,50),U(50,50),V(50,50)
COMMON/CONST/ G,PI,PI2.RAD,EPS,DX,DY,DT,DX2,DY2,T,SIGMA,
*M,N,N1,N2,M1,M2,AM,DD,IT,RH0,IWET,IDRY,ID
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          IF(FF.GT.O.O) GD TO 450
WRITE(6,451) I,J.D(I,JJ),COSI,SINI,U(I,J),V(I,J),RK,A
FORMAT(10x'FF IS NEGATIVE--DUTPUT I,J,D,COSI,SINI,U,V,RK,A'/,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  ZNEW=(COSI*DKDY(I, U)-SINI*DKDX(I, U)+Z(I, U-1)*DEN1-Z(I+1, U)*
*DEN2)/DEN
                                                                                                                                                                                                                                                                                                                                DEFINE STATEMENT FUNCTIONS - C.SS.DUDX,DUDY,DVDX,DVDY,DKDX,
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    CALL WVNUM(D(1,JJ),CDSI,SINI,U(1,J),V(1,J),RK,A)
ARG2=2.O*RK*D(1,JJ)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          IF(ABS(ZNEW-Z(1,J)).GT.(EPS*ABS(ZNEW))) IFLAG=O
                            ANGLE CALCULATES THE LOCAL WAVE DIRECTION
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     FAC(I, J)=U(I, J)*SINI-V(I, J)*COSI
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  J-1).LE.DD) G0 T0 210
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DEN1=(SINI-CGSI*FACI/FF)/DY
DEN2=(CGSI+SINI*FACI/FF)/DX
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            Z(I,J)=ZNEW
CO(I,J)=COS(Z(I,J))
SI(I,J)=SIN(Z(I,J))
IF(J.NE.2) GO TO 400
Z(I,N1)=Z(I,2)
CO(I,N1)=CO(I,2)
SI(I,N1)=SI(I,2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       DO 200 ITT=1, ITMAX
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      SINH2=SINH(ARG2)
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               IF(D(I, J-1)
COSI=C(I, J)
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*TAUBY(50,50),TAUSX(50,50),TAUSY(50,50)
COMMON/REF/ZZ(50,50),HNEW(50,50),RKA(50,50)
COMMON/CONST/ G.PI.PI2,RAD,EPS.DX.DY,DI.DX2,DY2,T.SIGMA,
*M.N.N1,N2,M1,M2,AM,DD,II,RHD,IWET,IDRY,ID
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**H(50.50),CG(50.50),S(50.50),HBREAK(50.50),IB(50.50),DDDX(50.50),
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*H(50,50),CG(50,50),S(50,50),HBREAK(50,50),IB(50,50),DDDX(50,50),
*DDDY(50,50),W(50,50),Y(50,50)
COMMON/VAL/ETA(50,50)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     THIS SUBROUTINE CALCULATES SURFACE SHEAR STRESS BY VAN DORN'S METHOD, AND AN AVERAGE BOTTOM SHEAR STRESS USING A SMALL CURRENT ASSUMPTION
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               DGRAD CALCULATES THE SPATIAL GRADIENTS IN DEPTH AFTER EACH UPDATING OF THE TOTAL DEPTH
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              SUBROUTINE TAUSB (WIND, WINANG, CF, ITO)
                                                                                                                                            GO TO 610
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       DDDX(I,1)=DDX(I,N)
DDDY(I,1)=DDDY(I,N)
DDDX(I,2)=DDDX(I,N1)
DDDX(I,2)=DDDX(I,N1)
DDDX(I,N2)=DDDX(I,3)
DDDY(I,N2)=DDDX(I,3)
                                                                                                                    RETURN
                           SI(1,J) = SI(1,K)

CO(1,J) = CO(1,K)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              SUBROUTINE DGRAD
                                                                                                                 IF (L .GT. 3)
IF (L .EQ. 3)
Z(I,J)*Z(I,K)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  ₹
                                                                                                                                                                                                                                                                                                                                                            GO TO 45
                                                                                                                                                                                                                                                                   GO TO 45
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    CONTINUE
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CALCULATE WIND SHEAR STRESS	IF(IT.GT.ITO+1) GO TO 21	VANCUN=1.1E-06 IF (WIND .GE.7.2) VANCON = 1.1E-06+2.5E-06*((17.2/WIND)**2	- WIND*COS(WINANG)	WINDY = WIND*SIN(WINANG)	20 7	20 I •		TAUSY(I, U) = CON+ *EINDY	CONTINUE		ALCOLAIL BUILDM FRICILUM AL EACH GRID PUIN	C		DO 40 I = IWET.M1	) <b>*</b> (5.	5		DO 700 I * 1,3	` <b>.</b>	* TAUBX	TAUBY(I	_	N2) = TAUBY(	CONTINUE	אני ומאַא האס		SUBROUTINE UCALC			USING THE FINITE DIFFERENCE EQUATIONS	NOTE THAT ALL DEPTHS LISED ARE DEFSET BY -DY			COMMON D(50,50),U(50,50),V(50,50),Z(50,50),SI(50,50),CO(50,50),	50,50),CG(50,50),S(50,50),HBREAK(50,50),IB(50,50),DDDX(50	MI(30,30),#(30,30),1(30,30)	WMON/STRESS/SIGXX(50,50).SIGYY(50.50).SIGXY(50,50).TAUBX(	UBY(50,50), TAUSX(50,50), TAUSY(50,50)	CDMMDN/REF/ZZ(50,50).HNEW(50,50),RKA(50,50)	MMMON/CONSI/G,PI,PIZ,KAD,EPS,UX,UY,UI,UXZ,UYZ,I,SIGMA,	E.N.N.'NZ.BI.EZ.ME.DO.I.'RTO.IEE'.IOR'.IU		DO 21 I=IWET,M-1	DBAR = (D(1,K)+D(1-1,K))/2	1,U) = U(I,U) +DT*((ETA(I-1,U) - ETA(I,U))*G/DX+(SIGXX(I-	X(I, U))/(DX*RHO*DBAR ) - (SIGXY(I, U+1)-SIGXY(I, U-1)+SIGX	2+1}-SIGXY(I-1,J-1))/(4.*DY*RHO*DBAR)+(IAUSX(I,J)+IAUSX(I-1,J))/(2. 3*DHO*DBAD)-(IAUBX(1.1)+IAUBX(I.4.1))/(3.*DHO*DBAD))	TERT	DBAR * (D(I.K) + D(I.K-1))/2.0	2006 (7 To 7 TO 2006) 26/01/21 PARTS (7 TO 10 TO
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0 60 (1.2) ((1.2) ((1.2) ((1.2) ((1.2) ((1.1) (	9 69 7	***	OUNDARY C
V(I.N2) = V(I.3) V(I.N2) = V(I.N1) V(I.N2) = V(I.N1) V(I.12) = V(I.N1) V(I.13) = V(I.N1) D( 69 1=1,M V(I.J) = V(I.J) = V(I.J) + V(I.J) + V(I.J) + V(I.J) = V(I.M V(I.J) = V(I.M) D( 69 1=1,M V(I.M) = V(I.M) D( 70 1=1,M D	60 60 60 1	f 1 3	M,1*I 09 00
(V(1.2) = V(1.N) V(1.1) = V(1.N) V(1.1) = V(1.N) (D 69 1=1.N) DD 69 1=1.N V(1.1)=(V(1.J)+V(1.J)+V(1.J+V(1.J+V(1.J+V(1.J))/2.0 V(1.J)=(V(1.J)+V(1.J)+V(1.J)+V(1.J)/2.0 V(1.N)=(V(1.J)=V(1.J) V(1.N)=(V(1.J)=V(1.J) V(1.N)=(V(1.J)=V(1.J) V(1.N)=(V(1.J)=V(1.J) V(1.N)=(V(1.J)=V(1.J) V(1.N)=(V(1.J)=V(1.J) V(1.N)=(V(1.J)=V(1.J) V(1.N)=(V(1.J)=V(1.J) V(1.N)=(V(1.J)=V(1.J) V(1.N)=(V(1.J)=V(1.J) V(1.N)=(V(1.J)=V(1.J) V(1.N)=(V(1.J)=V(1.J) V(1.N)=(V(1.J)=V(1.J) V(1.N)=(V(1.J)=V(1.J)=V(1.J) V(1.N)=(V(1.J)=V(1	09 60 60 1		V(1,N2) = V(1,3)
U(i; i) = U(i; Ni)  60 U(i; i) = U(i; Ni)  10 69 U(i; i) = U(i; Ni)  10 69 U=1, MI  10 60 U(i; i) = U(i; Ni)  10 60 U=1, MI  10 0 63 U=2, MI  10 (M, u)=(U(i, u)+U(i+1, u))/2.0  10 (M, u)=(U(i, u)+V(i, u)+V(i, u)+1)/2.0  10 0 0 1 = 1, MI  11 N(i, u)=(V(i, u))  12 W(i, u)=(V(i, u))  13 W(i, u)=(V(i, u))  14 W(i, u)=(V(i, u))  15 W(i, u)=(V(i, u))  16 W(i, u)=(V(i, u))  17 W(i, u)=(V(i, u))  18 W(i, u)=(V(i, u))  19 W(i, u)=(V(i, u))  10 W(i, u)=(V(i, u))  11 W(i, u)=(V(i, u))  12 W(i, u)=(V(i, u))  13 W(i, u)=(V(i, u))  14 W(i, u)=(V(i, u))  15 W(i, u)=(V(i, u))  16 W(i, u)=(V(i, u))  17 W(i, u)=(V(i, u))  18 W(i, u)=(V(i, u))  19 W(i, u)=(V(i, u))  10 W(i, u)=(V(i, u))  10 W(i, u)=(V(i, u))  10 W(i, u)=(V(i, u))  11 W(i, u)=(V(i, u))  12 W(i, u)=(V(i, u))  13 W(i, u)=(V(i, u))  14 W(i, u)=(V(i, u))  15 W(i, u)=(V(i, u))  16 W(i, u)=(V(i, u))  17 W(i, u)=(V(i, u))  18 W(i, u)=(V(i, u))  19 W(i, u)=(V(i, u))  10 W(i, u)=(V(i, u))  10 W(i, u)=(V(i, u))  11 W(i, u)=(V(i, u))  11 W(i, u)=(V(i, u))  12 W(i, u)=(V(i, u))  13 W(i, u)=(V(i, u))  14 W(i, u)=(V(i, u))  15 W(i, u)=(V(i, u))  16 W(i, u)=(V(i, u))  17 W(i, u)=(V(i, u))  18 W(i, u)=(V(i, u))  19 W(i, u)=(V(i, u))  10 W(i, u)=(V(i, u))  10 W(i, u)=(V(i, u))  11 W(i, u)=(V(i, u))  11 W(i, u)=(V(i, u))  12 W(i, u)=(V(i, u))  13 W(i, u)=(V(i, u))  14 W(i, u)=(V(i, u))  15 W(i, u)=(V(i, u))  16 W(i, u)=(V(i, u))  17 W(i, u)=(V(i, u))  18 W(i, u)=(V(i, u))  18 W(i, u)=(V(i, u))  19 W(i, u)=(V(i, u))  10 W	09 60 60 1		V(1.2) = V(1.0)
00 (01.1) = V(1.N)  00 69 1=1,M1  00 69 0=1,M1  00 79 1=1,M1  V(1.J)=V(1.J)+V(1.J+1)/2.0  69 CONTINUE  00 79 1=1,M1  V(1.N)=V(1.M)  10 19 1=1,M1  V(1.N)=V(1.M)  10 90 1=1,M2  M(1.N)=V(1.M)  10 90 1=1,M2  M(1.N)=V(1.M)  10 90 1=1,M2  M(1.N)=V(1.M)  10 90 1=1,M2  M(1.N)=V(1.M)  10 0 0 0 1=1,M2  M(1.N)=V(1.M)  10 0 0 0 1=1,M2  M(1.N)=V(1.M)  10 0 0 0 1=1,M2  M(1.N)=V(1.M)  10 0 0 1=1,M2  M(1.N)=V(1.M)  10 0 1 1=1,M2  M(1.N)=V(1.M)  M(1.N)=V(1.M)  M(1.N)=V(1.M)=V(1.M)  M(1.N)=V(1.M)  M(1.N)=V(1.M)=V(1.M)  M(1.N)=V(1.M)  M(1.N)=V(1.M)=V(1.M)  M(1.N)=V(1.M)  M(1.N)=V(1.M)=V(1.M)  M(1.N)=V(1.M)  M(1.N)=V(1.M)  M(1.N)=V(1.M)  M(1.N)=V(1.M)  M(1.N)=V(1.M)  M(1.N)=V(1.M	60 63		U(1,2) = U(1,N1)
DD 69 1=1,M1  DD 69 1=1,M1  U(M, J)=0(1,J)+U(1+1,J))/2.0  W(I,J)=(U(I,J)+V(I,J+1))/2.0  W(I,J)=(U(I,J)+V(I,J+1))/2.0  W(I,M2)=V(I,D)  W(I,M3)=V(I,D)  W(I,M3)=V(I,D)  W(I,M3)=V(I,D)  W(I,M3)=V(I,D)  W(I,M3)=V(I,M3)  W(I,M3)=V(I,M3)=V(I,M3)  W(I,M3)=V(I,M3)  W(I,M3)=V(I,M3)=V(I,M3)  W(I,M3)=V(I,M3)=V(I,M3)  W(I,M3)=V(I,M3)=V(I,M3)  W(I,M3)=V(I,M3)=V(I,M3)  W(I,M3)=V(I,M3)=V(I,M3)  W(I,M3)=V(I,M3)=V(I,M3)  W(I,M3)=V(I,M3)=V(I,M3)  W(I,M3)=V(I,M3)  W(I,M3)=V(I,M3)=V(I,M3)  W(I,M3)=V(I,M3)=V(I,M3)  W(I,M3)=V(I,M3)=V(I,M3)  W(I,M3)=V(I,M3)=V(I,M3)  W(I,M3)=V(I,M3)=V(I,M3)  W(I,M3)=V(I,M3)=V(I,M3)  W(I,M3)=V(I,M3)=V(I,M3)  W(I,M3)=V(I,M3)  W(I,M4)=V(I,M4)=V(I,M3)  W(I,M4)=V(I,M4)=V(I,M3)  W(I,M4)=V(I,M4)=V(I,M3)  W(I,M4)=V(I,M4)=V(I,M4)  W(I,M4)=V(I,M4)=V(I,M4)	09 08 1	1	V(1, 1)
U(M, J) = 0.0  W(I, J) = (U(I, J) + U(I+1, J)) / 2.0  W(I, J) = (U(I, J) + U(I+1, J)) / 2.0  W(I, J) = (U(I, J) + V(I, J) + V(I, J+1)) / 2.0  W(I, J) = (U(I, J) + V(I, J) + V(I, J+1)) / 2.0  ES CONTINUE  DO 79 11.4  W(I, N) = V(I, M)  W(I, N	608	9	(1,1)
U(M, J)=0.0 W(I, J)=0.0 W(I, J)=(V(I, J)+V(I, J+I))/2.0 W(I, J)=(V(I, J)+V(I, J+I))/2.0 W(I, N)=(V(I, J))=(V(I, J)+V(I, J+I))/2.0 D0 79 1=1, M V(I, N)=(V(I, J))=V(I, N) W(I, I)=Y(I, N) W(I, I)=Y(I, N) W(I, I)=Y(I, N) W(I, I)=W(I, N) W(I, I)=W(I, N) W(I, I)=W(I, N) W(I, I)=W(I, N) W(I, N)=(V(M, J)+V(M, J+I))/2.0 RETURN END SUBROUTINE ETAS ETAS CALCULATES THE CORRECTION TO SETUP AND TOTAL DEPTH BASED ON CONSERVATION OF MASS  COMMON D(50, 50), U(50, 50), V(50, 50), IR(50,	60 60 1		E
W(I.J)=(U(I.J)+U(I+1.J))/2.0 69 CONTINE DO 79 I=1/M V(I.N2)=W(I.J) W(I.N2)=W(I.J) W(I.N2)=W(I.J) W(I.N2)=W(I.J) W(I.N2)=W(I.J) W(I.N2)=W(I.N) T9 W(I.,1)=W(I.N) DO 80 J=1.N+2  80 V(M.J)=(V(M.J)+V(M.J+1))/2.0  RETURN END COMMON D(SO.SO).V(M.J)=(V(M.J)+V(M.J+1))/2.0  ETAS CALCULATES THE CORRECTION TO SETUP AND TOTAL DEPTH BASED ON CONSERVATION OF MASS  COMMON D(SO.SO).V(SO.SO).V(SO.SO).SI(SO.SO).SI(SO.SO).CO(SO.SO). *H(50.SO).CG(SO.SO).W(SO.SO).Y(SO.SO).SIGAY(SO.SO).TAUBX(SO.SO).COMMON/VAL/ETA(SO.SO).Y(SO.SO).SIGAY(SO.SO).SIGAY(SO.SO).TAUBX(SO.SO).TAUSX(SO.SO).	60 80 1		O.O=(D.M)U
9 CONTINUE DO 79 1=1, M V(1, J)=V(1, J) V(1, J)=V(1, 3) V(1, J)=V(1, 3) V(1, J)=V(1, 3) V(1, J)=V(1, N) DO 80 -J=1, N+2 BO V(M, J)+V(M, J+1))/2.0  RETURN ETAS ETAS CALCULATES THE CORRECTION TO SETUP AND TOTAL DEPTH BASED ON CONSERVATION OF MASS  COMMON VSTRESS/SO, SO, SO, SO, SO, SO, SO, SO, SO, SO,	60 8 90 1		W(I,J)=(U(I,J)+U(I+1,J))/2.0
69 COMMINUE 69 CONTINUE 70 Y(I, N2)=Y(I, 3) W(I, N2)=Y(I, N) 79 W(I, N2)=Y(I, N) 80 V(M, J)=Y(W, J)+Y(W, J+I))/2.0 RETURN END 80 V(M, J)=Y(W, J)+Y(W, J+I))/2.0 RETURN ET OR CONSERVATION OF MASS  COMMINON D(50, 50), W(50, 50), W(50, 50), IR(50, 50), I	6 08		Y(I, J)=(V(I, J)+V(I, J+1))/2
V(I : N2) = v(I : 3)  V(I : N2) = v(I : N1)  79 W(I : 1) = v(I : N1)  80 V(M . J) = (v(M . J) + v(M . J + 1))/2 . 0  REFURN  ETURN	8 9 1	69	
Y(I, \(I_2\) = \(Y(I_1\))  Y(I, \(I_2\) = \(Y(I_1\))  Y(I, \(I_1\) = \(Y(I_1\))  Y(I, \(I_1\))  Y(I, \(I_1\) = \(Y(I_1\))  Y(I, \(I_1\))	8 9 1		CO 1 N) = ( N 1 )
Y(I.1)=Y(I.N)  DU 80 (J=1,N+2)  BO Y(M,J)=(V(M,J)+V(M,J+1))/2.0  RETURN  END  COMMON D(3-1,N+2)  COMMON D(50.50), U(50.50), V(50.50), IB(50.50), CD(50.50),  COMMON D(50.50), U(50.50), V(50.50), RREAK(50.50), IB(50.50), CD(50.50),  COMMON NAL/ALTAGO, SO), Y(50.50), Y(50.50), SIGXY(50.50), TAUBX(50.50),  COMMON VAL/ETAGO, SO), Y(50.50), RREAK(50.50), RAUBX(50.50),  COMMON VAL/ETAGO, SO), Y(50.50), TAUSX(50.50), SIGXY(50.50), TAUBX(50.50),  COMMON VAL/ETAGO, SO), Y(50.50), RREAK(50.50), TAUBX(50.50),  COMMON VAL/ETAGO, SO), Y(50.50), RREAK(50.50), SIGXY(50.50), TAUBX(50.50),  COMMON VAL/ETAGO, SO), Y(50.50), TAUSX(50.50), TAUBX(50.50),  COMMON VAL/ETAGO, SO), Y(50.50), RREAGO, SO), SIGXY(50.50), TAUBX(50.50),  COMMON VAL/ETAGO, SO), Y(50.50), RREAGO, SO), RAGO, SO), TAUBX(50.50),  COMMON VAL/ETAGO, SO), Y(50.50), Y(50.50), SIGXY(50.50), TAUBX(50.50),  COMMON VAL/ETAGO, SO), Y(50.50), Y(50.50), Y(50.50), TAUBX(50.50),  COMMON VAL/ETAGO, SO), Y(50.50), Y(50	80 8		Z(1.72)=(1.3)
79 W(I, i)=W(I,N) DO 80 J=1,N+2 80 Y(M,J)=V(M,J)+V(M,J)+V(M,J+1))/2.0 RETURN END  SUBROUTINE ETAS  ETAS CALCULATES THE CORRECTION TO SETUP AND TOTAL DEPTH BASED ON CONSERVATION OF MASS  COMMON D(50,50),U(50,50),V(50,50),Z(50,50)	90 0		
DD 80 J=1,N+2  80 Y(W,J) = (V(W,J) + V(W,J) + Y(W,J) + Y(W,J) = (V(W,J) + V(W,J) + Y(W,J) + Y(W,J) + Y(W,J) = (V(W,J) + V(W,J) + Y(W,J) + Y(W,J) = (V(W,J) + Y(W,J) + Y(W,J) + Y(W,J) = (V(W,J) + Y(W,J) + Y(W,J) = (V(W,J) + Y(W,J) + Y(W,J) + Y(W,J) = (V(W,J) + Y(W,J) + Y(W,J) + Y(W,J) = (V(W,J) + Y(W,J) + Y(W,	8	79	
80 Y(M,J)=(V(M,J)+V(M,J+I))/2.0 RETURN END END ET LOR ET S	8		DO 80 J=1,N+2
ETAS CALCULATES THE CORRECTION TO SETUP AND TOTAL DEPTH BASED ON CONSERVATION OF MASS  COMMON D(SO, 50), U(50, 50), X(50, 50), Z(50, 50), Z(50, 50), A(50,	-	80	Y(M,J)=(V(M,J)+V(M,J+1))/2
ETAS CALCULATES THE CORRECTION TO SETUP AND TOTAL DEPTH BASED ON CONSERVATION OF MASS  COMMON D(50, 50), U(50, 50), V(50, 50), Z(50, 50), SI(50, 50), CO(50, 50), W(50, 50), TAUSX(50, 50)	_		RETURN
SUBROUTINE ETAS  ETAS CALCULATES THE CORRECTION TO SETUP AND TOTAL DEPTH BASED  ON CONSERVATION OF MASS  COMMON D(50,50), U(50,50), V(50,50), SI(50,50), COC(50,50),  *H(50,50), CG(50,50), V(50,50)  *DDDY (50,50), CG(50,50), V(50,50)  *DDDY (50,50), CG(50,50), V(50,50)  *COMMON/VAL/ETA(50,50)  *COMMON/VAL/ETA(50,50)  *COMMON/REFSS/SIGXX(50,50), TAUSY(50,50)  *TAUBY (50,50), TAUSX(50,50), TAUSX(50,50)  *TAUBY (50,50), TAUSX(50,50), TAUSX(50,50)  *COMMON/REFSS/SIGXX(50,50), TAUSY(50,50)  *TAUBY (50,50), TAUSX(50,50)  *M.N.N.N.N.M., M2.AM.DD, IT, RHO, IWET, IDRY, ID  *DO 1 1 = IWET, M1  *ETAQLD = ETA(1,J)  *ETAQLD = ETAOLD+T*(U(1,J)*(D(1,K)+D(1,L,K))/(2.*DX)) - U(1+1)  **ETAQLD + ETAOLD+T*(U(1,J)*(D(1,K)+D(1,K))/(2.*DX)) - U(1+1)  **ETAQLD + ETAOLD+T*(U(1,J)*(D(1,K)+D(1,K))/(2.*DY)) - U(1+1)  **ETAQLD + ETAOLD+T*(U(1,J)*(D(1,K)+D(1,K))/(2.*DY)) - U(1+1)  **ETAGLD + ETAOLD+T*(U(1,J)*(D(1,K)+D(1,K))/(2.*DY)) - U(1,K) - D(1,K) - D(1,K) - D(1,K) - D(1,K) - D(1,K) - D(1	_		END
ETAS CALCULATES THE CORRECTION TO SETUP AND TOTAL DEPTH BASED ON CONSERVATION OF MASS  COMMON D(56,50),U(50,50),V(50,50),Z(50,50),S(50,50),DDDX(50,50),  *H(50,50),C(50,50),V(50,50),HBREAK(50,50),BIG(50,50),DDDX(50,50),  *COMMON/VAL/ETA(50,50),TAUSX(50,50),TAUSX(50,50),TAUSX(50,50),TAUSX(50,50),TAUSX(50,50),TAUSX(50,50),RETA(50,50),TAUSX(50,50),TAUSX(50,50),RETA(50,50),TAUSX(50,50),RETA(50,50),TAUSX(50,50),RETA(50,50)  COMMON/STRES/SIGXX(50,50),TAUSX(50,50),RETA(50,50)  COMMON/CONST/ G.PI.PI2,RAD,EPS,DX,DY,DT,DX2,DY2,T,SIGMA,  *M.N.N1,N2,M1,M2,AM,DD,IT,RH0,IWET,IDRY,ID  D0 1 I=IWET,M1  ETACLD = ETA(1,J)  ETACLD = ETA(1,J)  ETACLD + ETA(1,J)  D0 1,K) = D(1,K) - ETACLD + ETA(1,J)  CONTINUE  BOUNDARY CONDITIONS  D0 2 I = 1,M  D(1,1) = D(1,N)  D(1,1) = D(1,N)  D(1,1) = D(1,N)  D(1,1) = D(1,N)	_	: .	
ETAS CALCULATES THE CDRRECTION TO SETUP AND TOTAL DEPTH BASED ON CDNSERVATION OF MASS  COMMON D(50,50).U(50,50),V(50,50),IB(50,50),DDDX(50,50),PDDX(50,50),REGO,50),R	_		SUBBOUTINE ETAS
ETAS CALCULATES THE CORRECTION TO SETUP AND TOTAL DEPTH BASED ON CONSERVATION OF MASS  COMMON D(50,50), U(50,50), V(50,50), Z(50,50), IB(50,50), DDDX(50,50), *H(50,50), CG(50,50), V(50,50), HBREAK(50,50), IB(50,50), DDDX(50,50), CG(50,50), V(50,50), HBREAK(50,50), IB(50,50), DDDX(50,50), CGMMON/VAL/ETA(50,50), V(50,50), TAUSX(50,50), TA	_	*	
ON CONSERVATION OF MASS  COMMON D(50,50),U(50,50),V(50,50),Z(50,50),Z(50,50),CO(50,50),V(50,50),U(50,5	_	*	ETAS CALCULATES THE CORRECTION TO SETUP AND TOTAL DEPTH BASED
COMMON D(50, 50), U(50, 50), Y(50, 50), Z(50, 50), Z(50, 50), CG(50, 50), CG(50, 50), Y(50, 50), Y(50, 50), Z(50, 50), Z(	<u>-</u>	*	ON CONSERVATION OF MASS
COMMON D(50,50).U(50,50),V(50,50),Z(50,50),SI(50,50),CO(50,50),* *H(50,50),CO(50,50),Y(50,50),HBREAK(50,50),IB(50,50),DDDX(50,50),* *DDDY(50,50),W(50,50),Y(50,50),BEAK(50,50),BDDX(50,50),DDDX(50,50),COMMON/VAL/ETA(50,50) COMMON/VAL/ETA(50,50) *TAUBY(50,50),TAUSX(50,50),SIGYY(50,50),SIGXY(50,50),TAUBX(50,50) COMMON/STRESS/SIGXX(50,50),SIGYY(50,50),SIGXY(50,50),TAUBX(50,50),TAUBX(50,50),HNEW(50,50),RKA(50,50) COMMON/REF/ZZ(50,50),HNEW(50,50),NX,AKA(50,50) COMMON/REF/ZZ(50,50),HNEW(50,50),DY,DT,DXZ,DYZ,T,SIGMA,* *M,N,N,N,NZ,M1,M2,AM,DD,IT,RHD,IWET,IDRY,ID D0 1 J = 3,N1 ETAGLD = ETA(I,J) ETA(I,J) = ETAGLD+DT*(U(I,J)*(D(I,K)+D(I-1,K))/(2.*DX) - V(I+1,K))/(2.*DX)+V(I,J)*(D(I,K-1)+D(I,K))/(2	_	*	
COMMON/STESS/SIGSO), V(SO, SO), V(SO, SO), SI(SO, SO), CU(SO, SO), V(SO, SO), V(SO, SO), V(SO, SO), V(SO, SO), COMMON/VAL/ETA(SO, SO), Y(SO, SO), SIGYY(SO, SO), SIGXY(SO, SO), TAUBY(SO, SO), TAUBY(SO, SO), TAUBY(SO, SO), TAUBY(SO, SO), TAUBY(SO, SO), COMMON/REF/ZZ(SO, SO), HNEW(SO, SO), COMMON/REF/ZZ(SO), CONDON/REF/ZZ(SO), COSO), CONDON/REF/ZZ(SO), CONDON/REF/ZZ(SO), CONDON/REF/ZZ(SO), COS	-	!	2 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
"TITOL 301, CG 150, 301, S 150, 501, TBKEAK (50, 501, IB(50, 501, DDDX (50, 502) "DDDY (50, 501, W (50, 501), Y (50, 501) "DDDY (50, 501, W (50, 501), Y (50, 501) "COMMON/VEFTESS/SIGXX (50, 501), SIGYY (50, 501), SIGXY (50, 501) "COMMON/CONSTY (50, 501), TAUSX (50, 501) "COMMON/CONSTY (6, PI, PI2, RAP, EPS, DX, DY, DT, DX2, DY2, T, SIGMA, "M, N, N1, N2, M1, M2, AM, DD, IT, RHO, IWET, IDRY, ID DO 1 J = 11 WET, M1 ETAGLD = ETA(I, J) ETAGLD = ETA(I, J) ETAGLD = ETA(I, J) ETAGLD = ETA(I, J) ETAGLD + ETAGLD + ETA(I, J) * (D(I, K) + D(I, K)) / (2, *DX) - V 2J + 1 * (D(I, K+1) + D(I, K)) / (2, *DX) + V (1, J) * (D(I, K+1) + D(I, K)) / (2, *DX) - V 2J + 1 * (D(I, K+1) + D(I, K)) / (2, *DX) + V (1, J) DO 1   ETAGLD + ETA(I, J) DO 2   ETAGLD + ETA(I, J) DO 2   ETAGLD + ETAGLD + ETAGLD + ETA(I, J) DO 3   ETAGLD + ETAG	_		COMMUN D(50,50), U(50,50), U(50,50), Z(50,50), Z(50,50),
COMMON/STRESS/SIGXX(50.50).TAUBX(50.50).COMMON/STRESS/SIGXX(50.50).TAUBX(50.50).COMMON/STRESS/SIGXX(50.50).SIGXY(50.50).SIGXY(50.50).TAUBX(50.50).COMMON/STRESS/SIGXX(50.50).TAUSX(50.50).COMMON/STRESS/SIGXX(50.50).TAUSX(50.50).COMMON/CONST/ G.PI.PI2.RAD.EPS.DX.DY.DT.DX2.DY2.T.SIGMA.*M.N.N1.N2.M1.M2.AM.DD.IT.RHD.IWET.IDRY.ID  DO 1 J= 11WET.M1.M2.AM.DD.IT.RHD.IWET.IDRY.ID  DO 1 J= 11WET.M1.M2.AM.DD.IT.RHD.IWET.IDRY.ID  DO 1 J= 11WET.M1.M2.AM.DD.IT.RHD.IWET.IDRY.ID  DO 1 J= 11WET.M1.M2.AM.DD.IT.RHD.IWET.IDRY.ID  ETAGLD = ETA(I.J)  ETAGLD = ETA(I.J)  ETAGLD + ETA(I.J) * (D(I.K) + D(I.K))/(2.*DX) - U(I+1) * (D(I.K) + D(I.K))/(2.*DX) + V(I.J) * (D(I.K) + D(I.N))/(2.*DX) + V(I.J) * (D(I.K) + D(I.N))/(2.*DX) + V(I.J) * (D(I.N) + D(I.N) + D(I.	_		*H(50,50),cg(50,50),S(50,50),HBREAK(50,50),IB(50,50),DDDX(50,50),
COMMON/STESS/SIGATO, 50, COMMON/STESS/SIGATO, 50, SIGYY(50,50), SIGXY(50,50), TAUBX(50,50) COMMON/STESS/SIGATO, 50), TAUSX(50,50), TAUSX(50,50), TAUSX(50,50), TAUSX(50,50) COMMON/REF/ZZ(50,50), TAUSX(50,50) COMMON/REF/ZZ(50,50), TAUSX(50,50) COMMON/REF/ZZ(50,50), TAUSX(50,50) COMMON/REF/ZZ(50,50), TAUSX(50,50) COMMON/CONST/ G.PI.PI2.RAP, EPS,DX,DY,DT,DX2,DY2,T,SIGMA, M.N.N.1,N2,M1,M2,AM,DD,IT,RHO,IWET,IDRY,ID DO 1 I=IWET,M1 E JOIN E TAOLD = ETACLD-DT*(U(I,J)*(D(I,K)+D(I-1,K))/(2.*DX) - U(I+1) ETACLD = ETACLD + ETA(I,J)*(D(I,K+1)+D(I,K))/(2.*DY)) E TAOLD = ETACLD + ETACLD + ETA(I,J)*(D(I,K-1)+D(I,K))/(2.*DY) - V 2J+1)*(D(I,K+1)+D(I,K))/(2.*DY)) D(I,K) = D(I,K) - ETACLD + ETA(I,J) CONTINUE  BOUNDARY CONDITIONS DO 2 I = 1,M D(I,I)=D(I,N) D(I,N) = D(I,N) D(I,N) = D(I,N)	_		*DDDY (50, 50) * W(50, 50) (7, 50, 50)
COMMON/STRESS/STREAM SOLOND, STREAM	_		COMMENDAL/OFFICE LA LOGGE TO A TABLE TO THE COMMENDAL ATTENDED TO THE COMMENDAL ATTEND
COMMON/REF/22(50.50), HNEW(50.50), RKA(50.50) COMMON/CONST/ G.PI.PI2.RAP.EPS.DX.DY.DT.DX2.DY2.T.SIGMA, *M.N.N1.N2.M1.M2.AM.DD.IT.RHO.IWET.IDRY.ID DO 1 J = 3.N1  K = J-1  DO 1 I=HET.M1  ETAQLD = ETA(I.J)  ETA(I.J)=ETAQLD+DT*(U(I.J)*(D(I.K)+D(I-1.K))/(2.*DX) - U(I+1  **(D(I.K)+D(I+1.K))/(2.*DX)+V(I.J)*(D(I.K-1)+D(I.K))/(2.*DY) - V  2J+1)*(D(I.K)+J+D(I.K))/(2.*DX)+V(I.J)  D(I.K) = D(I.K) - ETAQLD + ETA(I.J)  CONTINUE  BOUNDARY CONDITIONS  D(I.N) = D(I.N)	_		COMMONY SIRESUA SIGNATORY SIGNATURE
COMMON/CONST/ G.PI.PII.REM.SON.DY.DY.DY.DY.DY.SIGMA, *M.N.N1.N2.M1.M2.AM.DD.IT.RHO.IWET.IDRY.ID  DO 1 J = 3.N1  K = J-1  DO 1 I=IWET.M1  ETACLD = ETA(I.J)  ETA(I.J)=ETACLD+DT*(U(I.J)*(D(I.K)+D(I-1.K))/(2.*DX) - U(I+1  *(D(I.K)+D(I+1.K))/(2.*DX)+V(I.J)*(D(I.K-1)+D(I.K))/(2.*DY) - V  2J+1)*(D(I.K)+D(I+1.K))/(2.*DX)  D(I.K) = D(I.K) - ETACLD + ETA(I.J)  CONTINUE  BOUNDARY CONDITIONS  D(I.N) = D(I.N)	_		COMMON/DEF (727/R) R) INFEM/R) R) DV RC R)
**M.N.N.1.N.Y.N.N.N.N.N.N.N.N.N.N.N.N.N.N.N	_		COMMON ATT A LELOCOLO STATE TO COLO STATE TO
	_		COMMENTAL VIOLENCE AND
. ( \d.	ETACLD = ETA(I,J) ETACLD = ETA(I,J) ETACLD, = ETA(I,J) ETA(I,J)=ETACLD+OT*(U(I,J)*(D(I,K)+D(I-1,K))/(2.*DX) 1*(D(I,K)+D(I+1,K))/(2.*DX)) 1*(D(I,K)+D(I,K+1)+D(I,K))/(2.*DY)) D(I,K) = D(I,K) - ETACLD + ETA(I,J) 1*CONTINUE BOUNDARY CONDITIONS DO 2 I = 1.M D(I,1)=D(I,N) D(I,1)=D(I,N)		71.7.N.T. "N. "N. "M. "N. "M. "N. "M. "N. "N. "M. "N. "N. "N. "N. "N. "N. "N. "N. "N. "N
DO 1 I=IWET.M1 ETAOLD = ETA(I,J) ETA(I,J)=ETAOLD+DT*(U(I,J)*(D(I,K)+D(I-1,K))/(2.*DX) - U(I+1 1*(D(I,K)+D(I+1,K))/(2.*DX)+V(I,J)*(D(I,K-1)+D(I,K))/(2.*DY) - V 2J+1)*(D(I,K+1)+D(I,K))/(2.*DY)) D(I,K) = D(I,K) - ETAOLD + ETA(I,J) 1 CONTINUE BOUNDARY CONDITIONS D(I,N) = D(I,N) D(I,N) = D(I,N) D(I,N2) = D(I,3)	DO 1 = IWET,M1 ETAOLD = ETA(I,J) ETA(I,J)=ETAOLD+DT*(U(I,J)*(D(I,K)+D(I-1,K))/(2.*DX) 1*(D(I,K)+D(I+1,K))/(2.*DX)+V(I,J)*(D(I,K-1)+D(I,K))/(2.*DY)) D(I,K) = D(I,K) - ETAOLD + ETA(I,J) 1 CONTINUE BOUNDARY CONDITIONS D(I,1)=D(I,N) D(I,1)=D(I,N) D(I,1)=D(I,N)		C 6 5.7
ETACLD = ETA(I,J) ETA(I,J)=ETACLD+DT*(U(I,J)*(D(I,K)+D(I-1,K))/(2.*DX) - U(I+1) 1*(D(I,K)+D(I+1,K))/(2.*DX)+V(I,J)*(D(I,K-1)+D(I,K))/(2.*DY) - V 2J+1)*(D(I,K+1)+D(I,K))/(2.*DY)) D(I,K) = D(I,K) - ETACLD + ETA(I,J) 1 CONTINUE BOUNDARY CONDITIONS D(I, N) = D(I,N) D(I, N2) = D(I,3)	ETACLD = ETA(I,J) ETA(I,J)=ETACLD+DT*(U(I,J)*(D(I,K)+D(I-1,K))/(2.*DX) 1*(D(I,K)+D(I+1,K))/(2.*DX)+V(I,J)*(D(I,K-1)+D(I,K))/(2.*DY) 2/4+1)*(D(I,K+1)+D(I,K))/(2.*DY)) D(I,K) = D(I,K) - ETACLD + ETA(I,J) 1 CONTINUE BOUNDARY CONDITIONS DO 2 I = 1,M D(I,1)=D(I,N) D(I,1)=D(I,N)		
ETACL: J) = ETACLD+DT*(U(I,J)*(D(I,K)+D(I-1,K))/(2.*DX) - U(I+1)*(D(I,K)+D(I+1,K))/(2.*DX) - V(I+1)*(D(I,K)+D(I,K))/(2.*DY) - V 2J+1)*(D(I,K+1)+D(I,K))/(2.*DY)) 2J+1)*(D(I,K+1)+D(I,K))/(2.*DY)) 1 CONTINUE  BOUNDARY CONDITIONS DO 2 I = 1.M D(I,I)=D(I,N) D(I,I)=D(I,N) D(I,I)=D(I,N)	ETA(1.3) = ETA(1.3) (ETA(1.4) = ETA(1.4) (ETA(1.4) + D(1+1.K))/(2.40x) + V(1,3) + (D(1.K-1) + D(1.K))/(2.40x) 20+1) + (D(1,K+1) + D(1,K))/(2.40y)) D(1,K) = D(1,K) - ETA(1,3) CONTINUE BOUNDARY CONDITIONS DO 2 I = 1,M D(1,1) = D(1,3) D(1,1) = D(1,3)		E.   ATL   C   C   T   T   C   C   T   C   C   T   C   C
1*(D(1,K)+D(1+1,K))/(2.*bX)+V(1,J)*(D(1,K-1)+D(1,K))/(2.*bY) - V 2J+1)*(D(1,K+1)+D(1,K))/(2.*bY)) D(1,K) = D(1,K) - ETAGLD + ETA(1,J) D(1,K) = D(1,K) - ETAGLD + ETA(1,J)  CONTINUE  BOUNDARY CONDITIONS DO 2 I = 1.M D(1,1)=D(1,N) D(1,1)=D(1,N)	1*(D(1,K)+D(1+1,K))/(2.*DX)+V(1,J)*(D(1,K-1)+D(1,K))/(2.*DX) 2J+1)*(D(1,K+1)+D(1,K))/(2.*DY)) D(1,K) * D(1,K) - ETACLD + ETA(1,J) 1 CONTINUE  BOUNDARY CONDITIONS DO 2 I = 1,M D(1,1)=D(1,N) D(1,1)=D(1,N) D(1,1)=D(1,N)		- 11( 144
20+1)*(D(1,K+1)+D(1,K))/(2.*DY)) D(1,K) = D(1,K) - ETACLD + ETA(I,J) 1 CONTINUE  BOUNDARY CONDITIONS DO 2 I = 1,M D(1,1)=D(1,N) D(1,1)=D(1,N)	20+1)*(D(I,K+1)+D(I,K))/(2.*DY)) D(I,K) * D(I,K) - ETAOLD + ETA(I,J) 1 CONTINUE  BOUNDARY CONDITIONS DO 2 I = 1.M D(I,1)=D(I,N) D(I,1)=D(I,N)		\
-	-		
- ! !	-		20-1-1-01-1-X-1-1-01-1-X-1-1-1-1-1-1-1-1-
_	_		D(I,K) = D(I,K) - ETAOLD + ETA(I,U)
		-	CONTINUE
_		1	
DO 2 1 : D(I,1)=[	DO 2 I : D(I,1)=[	*.	BOUNDARY CONDITIONS
DO 2 I = 1,M D(I,1)=D(I,N) D(I,N2) = D(I.3)	DO 2 I = 1.M D(I,1)=D(I,N) D(I,N2) = D(I,3)	; 1 *	
D(I,1)=D(I,N) D(I,N2) = D(I,3)	D(1,1)=D(1,N) D(1,N2) = D(1,3)		N. 1 = 1 5 00
D(1.N2) = D(1.3)	D(1,N2) = D(1,3)		D(1,1)=D(1,N)
			D(1,N2) = D(1,3)

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00019270
00019280
00019290
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00019330
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NONLINEAR MODEL

_	VEARSHORE CIRCULATION MODEL NONLINEAR VERSION
	TOTAL TOTAL TOTAL TOTAL TOTAL OF TOTAL TOT
	GIVEN A PERIODIC DEPTH GRID AND MONOCHROMATIC WAVE FIFED AS INPUT.
	THE REFRACTION PROGRAM, INCLUDING THE EFFECTS OF WAVE-CURRENT
-	INTERACTION, WAS DEVELOPED BY NODA ET. AL. (1974). THE LINEAR
>	VERSION OF THIS PROGRAM WAS DEVELOPED BY BIRKEMEIER AND DALRYMPLE
_	(1977). THE PRESENT NONLINEAR VERSION UTILISES THE FULL NON-
_	LINEAR MOMENTUM EQUATIONS (EBERSOLE AND DALRYMPLE(1979). BOTTOM
ر* د	FRICTION IS CALCULATED USING THE METHOD DEVELOPED BY DALRYMPLE AND
ر. د	IU
; د	UMMUN U(50,50),U(50,50),V(50,50),S(50,50),SI(50,50),
	(50,507), cd(50,507), S(50,507), HEREAK(50,507), IB(50,507), UDDX(50,507),
*	DDV(50.50).W(50.50),V(50.50)
U	DMMDN/VAL/DP1(50,50).DM1(50,50).UP1(50,50).UM1(50,50).
>	P1(50.50), VM1(50.50), ETAP1(50,50), ETAM1(50,50), ETA(50,50)
U	OMMON/STRESS/SIGXX(50,50).SIGYY(50,50).SIGXY(50,50),TAUBX(50,50),
•	*TAUBY(50,50).TAUSX(50.30).TAUSY(50.50)
C	COMMON/REF/22(50.50) HNFW(50.50) RKA(50.50)
١	OMMON/EDDY/EXECTOR TO THE TOTAL TOTA
) C	COMMON/CONSTITUTION DAY EDGE FOR DY DV DI DV3 DV3 I STOMA
, 2	OWNERS CONST. G.F.I.T.E.F.E.F.E.F.E.F.E.F.E.F.E.F.E.F.E.F.E
E C	N.V. V. V.V. V. N. V.
י י י	195751 CN 1051 (50.50)
	NOTES ON DIMNING THE DEGGEDAM
	1. WAVE ANGLE IS MEASURED CLOCKWISE FROM THE +X DIRECTION
· *	
~	. WIND ANGLE IS MEASURED CLOCKWISE FROM THE -X DIRECTION
C* 3	3. ALL INPUT AND GUTPUT VARIABLES ARE IN MKS UNITS
C+ 4	. THE DEPTH GRID IS OFFSET -DY FROM ALL OTHER VARIABLE GRIDS
÷	
	DEFINITIONS OF QUANTITIES USED IN PROGRAM
<b>*</b> 0	
	1. CONSTANTS
*	CF - BOTTOM FRICTION COEFFICIENT (DARCY TYPE)
<b>ئ</b>	ICON - WINE
	EY - LATERAL EDDY COEFFICIENT, LONGSHORE DIRECTION
	IN - EDDY \
C* 2	. VARIABLE ARRAYS (VALUE AT EACH GRID LOCATION)
• °	D - TOTAL WATER DEPTH, STILL WATER + SETUP(ETA)
ڻ ٽ	DDDX, DDDY - LOCAL DERIVATIVES OF THE TOTAL DEPTH
	Z - WAVE ANGLE
* 5	CO - COS(Z)

0069	٠ ن			00690000
2000	<b>ံ</b> င်	REA		00001000
200		IB - BREAKING INDEX		0007100
2300		IN=4 MAVE IS BREAKING LOCALLY		00007300
7400	ڻ ن	CG - GROUP VELOCITY		00007400
7500	<b>*</b>	RKA - WAVE NUMBER		00001500
7600	ť	- X,Y VELOCITIES AT	KS	00001600
7700	<b>.</b>	- X,Y VELOCITIES AT CENTERS	DCKS	00001100
7800	*	NOTE THAT THE U,V AND W,Y ARRAYS ARE	ARRAYS ARE INTERCHANGED	00001800
7900	<b>*</b>	IN SEVERAL SUBROUTINES THROUGH THE COMMON STATEMENTS	OMMON STATEMENTS	00001900
8000	* t	S		0008000
26	ئ ئ	TAUGK, TAUGK = BUILDM SIRESSES		00008100
300	. ზ		RECTION	0008300
8400	, <b>č</b>			0000000
0000		3 LOCALLY DEFINED VARIABLES		000081000
8600				00008600
8700	ئ	t		0008100
8800	<b>*</b>	_	NTS	00088000
8900	ငံ	>	ONANTS	00680000
0006	*	~		00060000
9100	<b>.</b>	EPS - ACCURACY VALUE USED IN RELAXATION SCHEMES	HEMES	00000100
9200	• t			00003500
0066		· · · · · · · · · · · · · · · · · · ·	11.11.11.11.11.11.11.11.11.11.11.11.11.	00060000
9400				00009400
000		VARIABLES IU BE REAU INIU PRUGRAM		000000
9400		HAVE DADAMETEDS (DEEDWATED)		00003900
2000		- MAVE FAKAMETEKO (DEFEMETEK)		00/6000
0000	, <b>č</b>	T TANCOSO COLOSO SAN T		0000000
9900	5 2			0000000
5000		- WAVE MEIGH	FGBFES)	0001000
10200	, <b>*</b>	מינרי סריסייים	רמצורט)	00010200
10300		2. WIND PARAMETERS		00010300
10400		!		00010400
10500	<b>ئ</b>	WIND - WIN SPEED (METERS/SECOND)		00010500
10600	ပံ	Σ	-X (DEGREES)	00010600
10700				00010200
10800		3. GRID PARAMETERS		00010800
10900	• ပ	1		0001000
2 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	င် ငံ	M = NUMBER OF GRIDS IN X DIRECTION		00011000
2 2	, *	TO MEDITION OF THE POPULATION	(305)	
200	, <b>.</b>	NI BNIDARK DIAB	FDC)	200
11400	, <b>č</b>	- TIME	E(3)	00011400
11500	•ံ	DEX - SPECI	ON	00011500
11600	<b>.</b>			00011600
11700	<b>.</b>	READ DEPTH GRID	ATA FILE	00011700
11800	÷	SH PLANE	BEACH BASED ON INPUT BEACH SLOPE	00011800
11900	* i	AM - BEACH SLOPE		00011900
17000				00012000
12,000		4. PROGRAM CONTROL PARAMETERS		00012100
2200	د د	TTA TOTAL NIIMBED OF TTEDATIONS (INCLIDING ACCUMINATED	UDING ACCUMINATED	00017500
12400	, ບໍ່		TS USED)	00012400
12500	* °	ш	THE DEEP WATER WAVE	00012500
12600	ငံ			00012600
12700	ငံ	10 - DETERMINE IF DISSAPATION OF WAVE	ENERGY IS TO BE	00012700
12800	t i	INCLUDED		00012800
12900	ငံ ငံ		111111111111111111111111111111111111111	00012900
13000	<u>.</u>	*1, DISSAPATION DUE 10 VISCOSITY AND BOTTOM PERM	AND BOILOM PERM-	00013000

C	00013100	00013300	00013400	00013500	00013500	00013800	00013900	00014000	00014100	00014200	00014300	00014400	00014410	00014420	00014440	00014500	00014600	00014700	00014800	00015000	00015100	00015200	00015300	00015500	00015600	00015700	00015900	00016000	00016100	00016200	00016400	00016500	00016600	00016800	00016900	00011000	00017200	00017300	00017400	00017500	0001/600	00017800	00011900	00018000	00018200	00018300	00018500	00018600	0000
				CATES WARM C'M LICER CATES	SEE USERS MANUAL FOR INPUT FORMAT			RH0 = 1000.	G=9.81	PI = 3, 1415927	P12=P1 *2.0	RAD=180.0/PI	0.010	0.0=00 0.0=v=	VCON=0.0025		READ INPUT DATA	SOUTH THE CASE OF	PEAD(S: / ) T HO A	2. WIND PARAMETERS	READ(5, /) WIND, WINANG	3. GRID PARAMETERS	AEAD(3)/ JA.N.UX.UY.UY.UY.UY.TNUEX.AM	READ(5./)ITA,NHIGHT, ID, KSKIP		ဖ	WRITE(6.104)M.N. ITA	WRITE(6, 102)DX, DY, DT	WRITE(6,105) T.HO.A.AM	WRITE(6,106) WIND, WINANG WRITE(6,119) IDDEX IN MM	WRITE(6, 121) NHIGHT			CH=15H	DELTAT=DT	WINANG=WINANG/RAD	T-X-X	M2=M-2		DX2=DX*2	012=01-2. CIGMA=D10/T	51 CMM 712/ 1	EPSA=0.01	BASED ON VALUE OF "INDEX		GO TO (1,2,3) INDEX	READ DATA FROM FIE	DEAD(A 11G)	\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
	<b>.</b>	ů	• t	່ວ ເ	່ວ່	ڻ	C*-:									, + O	<b>ა</b>	<u>ئ</u> ڈ	ر'	ငံ	i	<u>*</u>	ť	)	် ပ	; ;	ر																			•	່ວ່		•

18900	(B t = 1 (CN t = 1 (1 1) (N t = 1 (CN t = 1 (1 1) 1)) *	00018900
19000	N, L=O. (O. I) (M). (N). (D. I). (O. I)	00019000
19100	*((DM1(I,U),U=1,N2),I=1,M).((ETAM1(I,U),U=1,N2),I=1,M),	000 19 100
19200	*((Z(1, C), C=1, N2), 1=1, M), ((H(1, C), C=1, N2), 1=1, M),	00019200
19300	*(N.1.NZ).I*(NZ)	00019300
0040		00019400
19600		00019500
19700	READ(8, 117) ITO	00019700
19800	DO 450 I=1.X	00019800
19900	D0 450 J=1,N2	00019900
20000	co(1,J)=cos(2(1,J))	00020000
20100		00020100
20200	450 CONTINUE	00020200
20300		00020300
20400	IF WAVE ANGLE IS LESS THAN	00020400
20900	C+ TELEPTOLIN PREVIOUS KON, ROLATE MAVE AND MIND MAGES	00020200
20700	TE(A GF 180 ) GO TO 3	00030300
20800	A I GOO I A	00020800
20900	WINANG=PI2-WINANG	00020000
21000	GG TO 31	00021000
21100		00021100
21200	INDEX=2, KEAD DEPIH GRID FROM INPUT FILE 5	00021200
2330		00021300
2 4 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	1	00021400
2150	C+ IF WAVE ANGIF IS IFS THAN 180 DECREES FID THE INDIT DEDTH	00021500
21700		00021200
21800	1	0002 1800
2 1900	IF(A.GT.180.) GO TO 161	0002 1900
22000	A=360 A	00022000
22 100	WINANG=PI2-WINANG	00022100
22200	DO 158 I=1,™	00022200
22300		00022300
22400	159 DST(I,J)=D(I,J)	00022400
22500	N.1=0 85 02	00022500
22600	K=(N-C)+1	00022600
22,00	150 TO 15	00022700
22800		00022800
23000	(*):1)(-)(N 1)(0)	00022900
23100	N1)=0(1N	00023000
23200	160 CONTINUE	00023200
23300	GO TO 146	00023300
23400	1	00023400
23500	C. INDEX-5, ENIBELISH PLANE BEACH	00023500
23700	3 DO 30 J=1,N2	00023200
23800		00023800
23900	$\overline{}$	00023900
24000	Ü	00024000
24100		00024100
24200	C* If WAVE ANGLE IS LESS HAN 180 DEGREES, KUTATE WAVE AND WIND ANGLE	00024200
24400	IF(A.GE.180.) GO TO 146	00024300
24500	A=360, -A	00024500
24600	WINANG=PI2-WINANG	00024600
24700	C*	00024700
24900	WALLE DEFINE GRID ON COLPUT IN TRACES OR	00024800
25000	146 WRITE(6,108)	00025000

25100	WRITE(6, 103)((D(I, J), J=1,N1), I=1,M)	00025100
25200	C* INITIALIZE ARRAYS	00025300
25400		00025400
25500		00025200
25600		00025600
25700	ETA(1, J)=0.0	00025700
25800	0.000	00022800
25900	O.O.T. TARMETS	00035300
26.00	C. 1.04.()	00025000
26200	O.C.(7, I.) IMA	00026200
26300	0.0×(1.1) W/	00026300
26400		00026400
26500	31 DO 15 I=1,X	00026500
26600		00026600
26700	_	00026700
26800	95 IWET=I	00026800
26900	IORY=IWET-1	00026900
27000	COLUMN DESCRIPTION OF THE PROPERTY OF THE PROP	00027000
27300	LUUP TUK	00027300
27300	TTELL	00027300
27400	TELITONE O) GO TO 4	00027300
27500		00027500
27600	CALL DGRAD	00027600
27700	CALL REFRAC(A.HO.1,NHIGHT.CF)	00027700
27800	CALL TAUSB(WIND.WINANG.CF.1TO)	00027800
27900	α.	00027900
28000		00028000
28 100		00028100
28200		00028200
28300	CALL UCALC(U.V.ISIEP)	00028300
28500		00028400
28600		00028600
28700	MCDUNT=AMOD(FLOAT(IT), 10.0)	00028700
28800	HO=HGT * TANH(FLOAT (IT) / (FLOAT (NHIC	00028800
28900	C IF(IT.LE.((NHIGHT*2.0)+5)) GO TO 12	00028900
29000	00 1	00023000
29100	12 CALL DGRAD	00029100
29200	CALL DEFENCE IN TTD1 AMIGHT CF)	00029200
29300	13 CALL TAINGROUND WINANG OF 1770)	00029300
29500	1F(11	00029500
29600	GO TO 52	00039600
29700	51 TSTEP=DT	00029700
29800		00029800
29900	CALL ETAS(ETAM1, TSTEP)	00053300
30000		00030000
30100	CALL UCALC(DM1,UM1,VM1,TSTEP)	00030100
30200	E: 11 00 00	00030500
30,400		00030300
30500		00030200
30600	U(1.1)=(U.1)	00030600
30700	V(I, J)=VP1(I, J)	00030100
30800	66 CONTINUE	00806000
30900		00606000
31000		00031000
365	CALL CUNITN	00031300
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*((U(I, J), J=1,N2), I=1,M), ((V(I, J), J=1,N2), I=1,M),
*((UM1(I, J), J=1,N2), I=1,M), ((VM1(I, J), J=1,N2), I=1,M),
*((DM1(I, J), J=1,N2), I=1,M), ((ETAM1(I, J), J=1,N2), I=1,M),
*((M(I, J), J=1,N2), I=1,M), ((H(I, J), J=1,N2), I=1,M),
*((RA(I, J), J=1,N2), I=1,M), ((Y(I, J), J=1,N2), I=1,M),
*((RKA(I, J), J=1,N2), I=1,M),
*((SIGXY(I, J), J=1,NZ), I=1,M),
*((SIGXY(I, J), J=1,NZ), I=1,M),
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*((SIGXX(I, J), J=1,M), ((SIGXX(I, J), J=1,M), MX), ((SIGXX(I, J), J=1,M), ((SIGXX(I, J), J=1,M), MX), ((SIGXX(I, J), J=1,M), ((SIGXX(I, J),
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   THE FOLLOWING WRITE STATEMENTS WRITE OUT THE RESULTS OF
                                                                                                                                                                                                                                                                                                                                                                                                                                                                    SUM=SUM+O.5*(W(I,J)**2+Y(I,J)**2)*D(I,J-1)
SUM=SUM+G*ETA(I,J)*(D(I,J-1)-O.5*ETA(I,J))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     WRITE (6,107)
WRITE (6,103) ((U(I,J), J = 1,N1),I=1,M)
WRITE (6,110)
WRITE (6,103) ((V(I,J), J = 1,N1),I=1,M)
WRITE (6,103) ((V(I,J), J = 1,N1),I=1,M)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            101 FORMAT (1X, "THE TOTAL ENERGY IS", F14.2)
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     WRITE(6,114)
WRITE(6,115)
WRITE(6,115)
DO 4001 I=1,M
DO 4001 0=1,N2
DO 4001 0=1,N2
WRITE(6,122)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    WRITE(6, 109)((ZZ(I,J),J=1,N1),I=1,M)
                                                                                                                                                                                                              CALL UCALC(OM1.UM1,VM1,TSTEP)
DO 57 I=1.N
DO 57 J=1.N2
ETA(I.J)=ETAP1(I.J)
D(I.J)=DP1(I.J)
U(I.J)=UP1(I.J)
V(I.J)=VP1(I.J)
CALL MOMEN
CALL UCALC(DM1,UM1,VM1,TSTEP)
IF(MCDUNT.EQ.O) GD TD 53
                                                                                                                                                                         CALL ETAS(ETAM1, TSTEP)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           SUBSEQUENT START-UP
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IF(L.NE.0)G0 T0 5
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                                                                                                                                                                                                                                                                                                                                                                                                                              DO 86 I=1,M
DO 86 J=2,N
                                                                                                          CALL ROLBAC
                                                                                                                                                    CALL CONTIN
                                                                CALL ROLBAC
                                                                                                                                                                                             CALL MOMEN
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RKA(I,J) = RK
IF (J.EQ.N) RKA(I,t)=RKA(I,J)
IF (J.EQ.2) RKA(I,N1)=RKA(I,J)
                                                                                                                                                                                                                                                                                                                                                                 SIGXY(M, U) = 2.0 * SIGXY(M1, U) - SIGXY(M2, U)
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                   ENERGY=0.125*RHO*G*(H(I,J)**2)
SIGX(I,J)=SIGX(I,J)*ENERGY
SIGY(I,J)=SIGY(I,J)*ENERGY
                                                                                 SIGXY(I, J) * SIGXY(I, J) * ENERGY
                                                                                                                       SIGY(I,1)=SIGX(I,N)
SIGY(I,1)=SIGY(I,N)
SIGX(I,2)=SIGX(I,N)
SIGX(I,2)=SIGX(I,N)
SIGY(I,2)=SIGX(I,N1)
SIGY(I,2)=SIGX(I,N1)
SIGX(I,N2)=SIGX(I,N1)
SIGX(I,N2)=SIGX(I,3)
SIGX(I,N2)=SIGX(I,3)
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SIGXY(M,N2)=SIGXY(M,3)
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IF(DEP.LE.DD) RETURN
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SINI=SI(I, J)
DO 3 J=3,N1
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                                                                                                                                                                                                                                                                                                                                  HEIGHT CALCULATES THE LOCAL WAVE HEIGHT AT EACH GRID LOCATION
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               X=RKA(1,J)*CF*SIGMA*H(1,J)/(6.*P1*(CH**3.-CH))
X=X+G*PERM*RKA(1,J)/(VISCOS*CH*CH)
                                                                                                                                         PECK(SINH2-ARG2*COSH2)/SINHSQ
DKDDX=RK*DDDX(I,JJ)+DEP*DKDX(I,J)
DKDDY=RK*DDDY(I,JJ)+DEP*DKDY(I,J)
Q=O.5*G/(C*RK*2)
DCDX=Q*(RK*SECHSQ*DKDDX-TA*DKDX(I,J))
DCDX*Q*(RK*SECHSQ*DKDDY-TA*DKDX(I,J))
DCGDX*P*DKDDX+FF*DCDX
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           SIGXX=(2.0*FF-0.5)*CC2+(FF-0.5)*SS2
SIGYY=(2.0*FF-0.5)*SS2+(FF-0.5)*CC2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                              CALL GROUP(I,J,DCGDX,DCGDY,FF)
DUDX=(W(I+1,J)-W(I,J))/DX
DUDY=(U(I,J+1)-U(I,J-1))/DX2
DVDX=(V(I+1,J)-V(I-1,J))/DX2
DVDX=(X(I+1,J)-Y(I,J))/DX2
DVDX=(Z(I+1,J)-Z(I-1,J))/DX2
DTDX=(Z(I+1,J)-Z(I-1,J))/DX2
 IF (J.EQ.3) RKA(I,N2)*RKA(I,J)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                      IF(D(I,J-1).LE DD) GO TO 499
                                                                                                                                                                                                                                                                              SUBROUTINE HEIGHT (ITMAX, CF)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   CH≈COSH(RKA(1,J)*D(1,J-1))
IF(1D.EQ.1) GO TO 3O1
                     HBREAK(I, J) = 0 12*PI2*TA/RK
COSH1=COSH(RK*DEP)
                                                                                                           C=SQRT(G*TA/RK)
FF=O.5*(1.0+ARG2/SINH2)
CG(1,J)=FF*C
                                           SECHSQ=1.0/(C0SH1**2)
ARG2=2.0*RK*DEP
                                                                                                                                                                                                                        DCGDY = P * DKDDY + F F * DCDY
                                                                SINH2=SINH(ARG2)
COSH2=COSH(ARG2)
          TA=TANH(RK+DEP)
                                                                                      SINHSQ=SINH2**2
                                                                                                                                                                                                                                                                                                                                                                                                                            VISCOS=1.0E-05
                                                                                                                                                                                                                                                                                                                                                                                                                                       PERM=1.06E-09
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                                                                                                                                                                                                                                                                                                                                                                                                                                                DO 500 I=2,M1
DO 500 J=2,N1
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                                                                                                  EE=E(I,J)
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                                             $(1, J) = CG(1, J) + (S1(1, J) *DTDX - CB(1, J) *DTDY) - (DUDX + DVDY) - (CB(1, J) *DC PY + DVDX + S1GYY *DVDX + S1GYY *DVDY) - X
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540 FORMAT(' RELAXATION FOR THE WAVE HEIGHT FAILED TO CONVERGE',
*'ON ROW', IS,'AFTER', IG,'ITERATIONS')
WRITE(6,541)(H(I.J),J=1,N2)
541 FORMAT(' LAST VALUES OF H ARE'/,10F13.5)
                                                                                                                                                                                                  CC1=(V(I,J)+CG(I,J)*SI(I,J))/DY

CC2=(U(I,J)+CG(I,J)*CD(I,J))/DX

HNEW(I,J)=(CC1+H(I,J-1)-CC2*H(I+1,J))/(CC1-CC2-S(I,J)/2.0)

IF (HNEW(I,J) LT. 0.0) GD TD 810

IF (HNEW(I,J) LE.HBREAK(I,J)) GD TD 850

HNEW(I,J)=HBREAK(I,J)
                                                                                                                                                                                                                                                                                               IF(ABS(HNEW(1,J))-H(1,J)).GT.(EPSH*ABS(HNEW(1,J)))) IFLAG=O BOUNDARY CONDITIONS
                                                                                                                                                                            IF(D(1,J-1) .LE. DD) GO TO 520
IB(1,J)=1
SIGX(I,J) = SIGXX
SIGY(I,J) = SIGYY
TAUXY=FF*SI(I,J)*CO(I,J)
SIGXY(I,J)=TAUXY
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      IF(IFLAG.EQ.1) GO TO 570
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                                                                                                                                                                                                                                                                                                                      IF (J.NE.2) GO TO 800
                                                                                                                                                                                                                                                                                                                                 HNEW(I,N1)=HNEW(I,U)
IB(I,N1)=IB(I,U)
                                                                                                                                                                                                                                                                                                                                                                             HNEW(I,N2)=HNEW(I,U)
                                                                                                                                                                                                                                                                                                                                                                                            IB(I,N2)=IB(I,J)
IF(J.NE.N) GO TO 802
                                                                                                                                                                                                                                                                                                                                                                     IF(J.NE.3) GO TO 801
                                                                                                                                                                                                                                                                                                                                                                                                                HNEW(I,1)=HNEW(I,J)
IB(I,1)=IB(I,J)
GO TO 520
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IB(I,2)=IB(I,J)
CONTINUE
                                                                                                                                          DO 580 ITT=1, ITMAX
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  DO 625 J=1,N2
H(I,J)=HNEW(I,J)
                                                                                             SIGXY(1,J)=0.0
                                                                                                                   DO 510 II=1,M2
                                                                                                                                                                  DO 520 J=2,N1
                                                                                 H(I,J)=0.0
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                                                                     GO TO 500
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                                                                                                                                                                                                                                                                                                                                                    C(I,J)=0.25*(CD(I+1,J)+CD(I-1,J)+CD(I,J+1)+CD(I,J-1))+0.125*((Z(I *+1,J)-Z(I-1,J))*(SI(I+1,J)-SI(I-1,J))*(Z(I,J+1)-Z(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(SI(I,J-1))*(
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     DUDX(I,J)=(W(I+1,J)-W(I,J))/DX
DUDY(I,J)=(V(I+1,J)-V(I-1,J))/DX2
DVDX(I,J)=(V(I+1,J)-V(I-1,J))/DX2
DVDX(I,J)=(Y(I,J+1)-Y(I,J)-Y(I,J)-X
F(I,J)=V(I,J)*COSI+V(I,J)*SINI + O.5*A*(1.O + ARG2/SINH2)/RK
DKDY(I,J)=(-(CQSI*DUDY(I,J) + SINI*DVDY(I,J))-A*DDDY(I,J-1)/SINH2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       DKDX(I.J)=(-(COSI*DUDX(I.J)+SINI*DVDX(I.J))-A*DDDX(I.J-1)/SINH2)/F
                                                       COMMON D(50,50),W(50,50),Y(50,50),Z(50,50),SI(50,50),CD(50,50),+H(50,50),CG(50,50),S(50,50),HBREAK(50,50),IB(50,50),DDDX(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W
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WRITE(6,451) I,J,D(I,JJ),COSI,SINI,U(I,J),V(I,J),RK,A
451 FORMAT(10X'FF IS NEGATIVE--DUTPUT I,J,D,COSI,SINI,U,V,RK,A'/.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            ZNEW=(COSI*DKDY(I,J)-SINI*DKDX(I,J)+Z(I,J-1)*DEN1-Z(I+1,J)*
                                                                                                                                                                                                                                                      DEFINE STATEMENT FUNCTIONS C.SS. DUDX, DUDY, DVDX, DVDY, DKDX
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 CALL WVNUM(D(I,JJ),COSI,SINI,U(I,J),V(I,J),RK,A)
ARG2=2.0*RK+D(I,JJ)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         IF(ABS(ZNEW-Z(I,J)) GT (EPSA*ABS(ZNEW))) IFLAG=O
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 FAC(I,J)=U(I,J)*SINI-V(I,J)*COSI
DO 200 ITT=1,ITMAX
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          DO 210 J=2,N1
IF(D(1,J-1).LE.DD) GO TO 210
COSI=C(1,J)
SINI=SS(1,J)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           450 FACI=FAC(I,U)
DEN1=(SINI-COSI*FACI/FF)/DY
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        DEN2=(COSI+SINI*FACI/FF)/DX
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       SI(I,J)=SIN(Z(I,J))
IF(J.NE.2) GD TO 400
Z(I,N1)=Z(I,2)
CO(I,N1)=CO(I,2)
SI(I,N1)=SI(I,2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      IF (J.NE.3) GO TO 401
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          Z(I, J)=ZNEW
CO(I, J)=COS(Z(I, J))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          DO 210 II=1, MWET
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  SINH2=SINH(ARG2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            DEN=DEN1-DEN2
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                                                                                                                                                                                                                                                                                               DKDY, FAC, F
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                GD TD 210
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90000	1F(U.NE.NI) GO TO 210	00069900
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2020	ONTINE SINITINE SINIT	00010200
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70500	9	00070500
20607		0000000
70700	220 FORMAT(" RELAXATION FOR THETA FAILED AFTER" 14.3X	00070700
70800		00010800
70900	STOP	0001000
71000	250 CONTINUE	00011000
71100	RETURN	00011100
71200	END	00011200
71300	1   1   1   1   1   1   1   1   1   1	00071300
1400		0007 1400
71500	SUBROUTINE WVNUM(D.COSI.SINI.U.V.RK.A)	0007 1500
71600		00071600
71700		00071700
71800	C* CORRENI IN ERACLION.	00071800
22000		00073000
72100	COMMON/CONST. C DI DIO DAD EDCH EDCA DY DY DY DY O I CIGMA	00072000
72200	CONTROL OF THE DO IT DIE TOOK OF THE CONTROL OF THE	00012100
72300	FPNX=0.001	00012300
72400	RK=P12/(T*SQRT(G*D))	00072400
72500	D0 100I=1,50	00072500
72600	A=SIGMA-U*RK*COSI-RK*V*SINI	00012600
72700	A2=A**2	00072700
72800	ARG=RK*D	00072800
72900	f 1=EXP(ARG)	00012900
33000		00073000
13700	SECHEL	000/3100
73300	T T T A NH ( A R G )	00073300
73400	FX=G*RX*II-A	00073400
73500	FFK=G*(ARG*SECH2+TT)+2.0*(U*COSI+V*SINI)*A	00073500
73600	RKNEW=RK-FK/FFK	00013600
73700	IF(ABS(RKNEW-RK).LE.(ABS(EPSK*RKNEW))GD TD 110	00073700
73800		00073800
73900	100 CONTINUE	00013900
74000	WRITE(6, 101)I, RK, T, D, U, V	00074000
74100	101 FORMAT(" INTERATION FOR K FAILED TO CONVERGE: I.K.D.U.V"	00074100
35	10.01	000/4200
74400	מחוומט	000/4300
74500	110 RK=RKNEW	00074500
74600		00074600
74700		00074700
74800	C* CHECK IF RK NEGATIVE, THIS CONDITION CAN ARISE IF LOCAL CURRENT C* 15 TON STRONG	00074800
75000	1	000/4900
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                                                                                                                                                                                                        COMMON D(50,50),U(50,50),V(50,50),Z(50,50),SI(50,50),CO(50,50),
**H(50,50),CG(50,50),S(50,50),HBREAK(50,50),IB(50,50),DDDX(50,50)
*,DDDY(50,50)
COMMON/CONST/ G,PI.P12.RAD,EPSA,DX,DY,DT,DX2,DY2.T,SIGMA,*M,N,N1,N2,M1,M2,AM,DD,IT,RHG,IWET,IDRY,ID
                                                                                                                                          SNELL CALCULATES THE FIRST GUESS OF THE REFRACTION ANGLE AT EACH GRID, AND ALSO THE WAVE HEIGHT AT THE LAST GRID(M) FOR EACH ITERATION THAT THE DEEPWATER WAVE IS BUILDING UP.
                                                                                                                                                                                                                                                                                                                     CALL WVNUMD(1, U-1), -1.0,0.0,0.0,0.0,0.0,RK,A)

AA = RK* D(1, U-1)

ANG = ARSIN(SIN(THETAD)*TANH(AA))

ANG = PI-ANG

ARG = 2.0*AA

SHOAL = SQRT(1.0/(TANH(AA)*(1.0*ARG/SINH(ARG))))

REF = SQRT(COS(THETAD)/COS(ANG))

WVHT = HH*SHOAL*REF
IF(RK.GT.O.O)GG TO 120
WRITE(6,130)D,COSI,SINI,U,V,RK,A
130 FORMAT(" RK IS NEGATIVE: D,COSI,SINI,U,V,RK,A",
                                                                                                                   SUBROUTINE SNELL (THETAD, HH, ITER)
                                                                                                                                                                                                                                                                                                                                                                                                                                        [F(WVHT GT HB) WVHT = HB
                                                                                                                                                                                                                                                                                                                                                                                                                             HB = 0.12*TANH(AA)*P12/RK
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SS = SIN(ANG)
CC = COS(ANG)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             5 DO 60 I = 1,M
H(I,J) = H(I,K)
IB (I,J) = IB(I,K)
Z(I,J)=Z(I,K)
SI(I,J) = SI(I,K)
CO(I,J) = CO(I,K)
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DD 600 J=2.N1
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SI(I,J) = SS

CO(I,J) = CC
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IB(I,J) = IN
                                                   CALL EXIT
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IF (L .GT . 3) RETURN  IF (L .Eq. 3) GO TO 610  L * 2  U * 2  K = N  GO TO 45  GO TO 45  GO TO 45  RETURN  END	COMMON TREE SURFACE SHEAR STRESS BY VAN DORN'S  WITHOU AND AUGACHATES SURFACE SHEAR STRESS BY VAN DORN'S  WITHOU AND AUGACHATES SURFACE SHEAR STRESS BY VAN DORN'S  WITHOU AND AUGACHATES SURFACE SHEAR STRESS BY THE WETHOD OF  COMMON OFFICE SON, U(50, 50), V(50, 50), Z(50, 50), S(50, 50)
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              COMMON/CONST/ G,PI.PI2,RAD.EPSH.EPSA.DX,DY,DT.DX2,DY2,T.SIGMA,
COMMON/CONST/ G,PI.PI2,RAD.EPSH.EPSA.DX,DY,DT.DX2,DY2,T.SIGMA,
*M.N.Ni.NZ.M1,MZ,AM,DD,IT,RHG.IWET.IDRY,ID
DO 6O 1 = 2,M1
DO 6O J = 3,N1
DDDX(I,J) =-(D(I-1,J)-D(I+1,J))/(2.*DX)
IF(J.EQ.N1) GD 70 61
DDDXED(I,J-2)-8.O*D(I,J-1)+8.O*D(I,J+1)-D(I,J+2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                 CALCULATE THE SPATIAL GRADIENTS IN TOTAL DEPTH AFTER EACH
UPDATING OF THE TOTAL DEPTH
 EXPR4=2.0*EXPR1
WM1=(UM1(I,J)+UM1(I+1,J))/2.0
WM1=(UM1(I,J)+UM1(I,J+1))/2.0
WM1=(UM1(I,J)+UM1(I,J+1))/2.0
EXPR3=WM1**2
EXPRG=YM1**2
DELX=0.0
DO 2 LL=1,L+1,1
B(LL)=SQRT(EXPR3+EXPRG+(UMAX*COS(DELX))**2+COS(DELX)*
*(WM1*EXPR3+YM1*EXPR4))
GG(LL)=(YM1*EXPR3+COS(DELX))**B(LL)
F(LL)=(WM1*EXPR3+COS(DELX))**B(LL)
CCONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     DDY=D(I,N-1)-8.0*D(I,N)+8.0*D(I,N+2)-D(I,4)
DDDY(I,J)=DDY/(12.0*DY)
CONTINUE
                                                                                                                                                                                                                    SUMM=SUMM+GG(MM-1)+4.0*GG(MM)+GG(MM+1)
                                                                                                                                                                                                       SUM=SUM+F(MM-1)+4.0*F(MM)+F(MM+1)
                                                                                                                                                                                                                                                                                        TAUBX(I,i) = TAUBX(I,N)
TAUBX(I,N1) = TAUBX(I,2)
TAUBX(I,N2) = TAUBX(I,3)
TAUBY(I,1) = TAUBY(I,N)
TAUBY(I,N1) = TAUBY(I,N)
TAUBY(I,N2) = TAUBY(I,2)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    DDDY(I, J)=DDY/(12.0*DY)
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TAUBY(I,J)≈SUMM*VALUE
CONTINUE
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DDDy(1,1)=DDDy(1,N)
DDDx(1,2)=DDDx(1,N1)
DDDy(1,2)=DDDy(1,N1)
DDDx(1,N2)=DDDx(1,N1)
                                                                                                                                                                                                                                                                                                                                                                                                                          SUBROUTINE DGRAD
EXPR3=2.0*EXPR2
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                                                                                                                                                                                SUMM=0.0
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	EQUATIONS  COOS4600  COOS4600  COOS4600  COOS4600  COOS4600			CDMMDN/EDDY/EX(50.50); V.CON. CDMMDN/EDDY/EX(50.50); V.CON. CDMMDN/CDDY/EX(50.50); V.CON. CDMDN/CDDY/EX(50.50); V.CON. CDMMDN/CDDY/EX(50.50); V.CON. CDMMDN/CDDY/EX(50.50); V.CON. CDMMDN/	1 -1WET+1)*DX)*VCON*SQRT(G*DM1(I,J-1)) 00096000 EX(I,J)=.875			*U(I,J))*(U(I+1,J)+U(I,J))-((D(I,K)+D(I-1,K))*U(I,J)+ *(D(I-1,K)+D(I-2,K))*U(I-1,J))*(U(I,J)+U(I-1,J))/(8.0*Dx) 00097400 UP1(I,J)=UP1(I,J)+(D(I,K)+D(I,K))*(I,J+I)+(D(I-1,K+I)+	(1-1,0+1)*(u(1,0)+u(1,0+1)) ((u(1,0+1))* 1-1,K)+u(1-1,K-1))*(u(1,0)+u(1,0+1)) (0097700 00097700	1(I,J)+(TAUBX(I,J)+TAUBX(I-1,J))/(2.0*R!d) 1(I,J)+(SIGX(I,J)-SIGX(I-1,J))/(DX*RHD)+(SIGXY(I, I,J-1)+SIGXY(I-1,J+1)-SIGXY(I-1,J-1))/(4.0*DY*RHD)	*VM1(I-1,U+1))*(EX(I,U+1)+EX(I,U)+EX(I-1,U)+EX(I-1,U+1))- *(VM1(I,U)-VM1(I-1,U))*(EX(I,U)+EX(I,U-1)+EX(I-1,U-1)+	*EX(I-1,J))/(8.0*Dx*DY)  000991000  vp(I,J,J))/((I+1,K)+D(I,K))*U(I+1,J)+(D(I+1,K-1)+D(I,K-1))*  vu(I+1,J-1))*(V(I+1,J)+V(I,J))-((D(I,K)+D(I-1,K))*U(I,J)+  00099100  *(D(I,K-1)+D(I-1,K-1))*U(I,J-1))*(V(I,J)+V(I-1,J))/(8.0*DX)  00099300	IF (K.EQ.2) GO TO 83 GO TO 84 GO TO 84 SOUPPE(I.J)=VP(I(I.J)+(((D(I.K+1)+D(I.K))+V(I.J+1)+(D(I.K)+ *D(I.K-1))*V(I.J))*(V(I.J+1)+V(I.J)-((D(I.K)+D(I.K-1)))*(R.P))* *VII.J1+D(I.K-1))*V(I.J-1)*V(I.J-1)*(V(I.J)+V(I.J-1))*(R.P))*
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	94700 C* EQUATIONS 94700 C* 94800 C*	)	7 4 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0		96000 D0 96 J=3,N1 96100 EX(I,J)=((I-IWET+1)*DX)*V 96200 IF(I,GE.12) EX(I,J)=.875	0	99		9/600 9/600 9/700 * V(I,J)+(D(I-1,K)+D(I-1,K) 97800 9/800 */(8.0*0Y)	98200 UP1(I,J)=UP1(I,J)+(TAUBX( 98300 UP1(I,J)=UP1(I,J)+(SIGX(I 98400 *J+1)-SIGXY(I,J-1)+SIGXY(I			99400 IF (K.EQ.2) GO TO 83 99500 GO TO 84 99600 83 VP1(I,J)=VP1(I,J)+(((D(I, 99700 *D(I,K-1))*V(I,J))*(V(I,J) 99800 *V(I,J)*V(I,J))*(V(I,J)

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                   00100100
                                                                                                                                                                                                                                                                                                                                                                                                                   ETAS CALCULATES THE CHANGE IN MEAN WATER LEVEL DUE TO WAVE ACTION
84 VP1(I,J)=VP1(I,J)+(((D(I,K+1)+D(I,K))*V(I,J+1)+(D(I,K)+
*D(I,K-1))*V(I,J))*((V(I,J+1)+V(I,J))-((D(I,K)+D(I,K-1))*
*V(I,J)+(D(I,K-1)+D(I,K-2))*V(I,J-1))*(V(I,J)+V(I,J-1))/(8.0*DY)
85 VP1(I,J)=VP1(I,J)+(D(I,K)+D(I,K-1))*(ETA(I,J)-ETA(I,J-1))*
*(G/(2.0*DY))
                                                                                                                                                                                                                                                                                                                                                                                                                                                               VP1(I.J)=VP1(I.J)-(TAUSY(I.J)+TAUSY(I.J-1))/(2.O*RHO)
VP1(I.J)=VP1(I.J)+(TAUBY(I.J)+TAUBY(I.J-1))/(2.O*RHO)
VP1(I.J)=VP1(I.J)+(TAUBY(I.J)+TAUBY(I.J-1))/(2.O*RHO)
VP1(I.J)=VP1(I.J)+(SIGXY(I-1,J-1)+SIGXY
*(I+1,J)-SIGXY(I-1,J))/(4.O*RHO*DX)+(SIGY(I.J)-SIGY(I.J-1))
*/(RHO*DY)
VP1(I.J)=VP1(I.J)-(DM1(I.K)+DM1(I.K-1))*((EX(I+1,J-1)+EX(I-1))-(FX(I-1,J)+EX(I-1,J)+EX(I-1,J)+EX(I-1,J))-(FX(I-1,J)+EX(I-1,J)+EX(I-1,J)+EX(I-1,J))-(FX(I-1,J)+EX(I-1,J)+EX(I-1,J))-(FX(I-1,J)+EX(I-1,J)+EX(I-1,J)-VP1(I.J)-(FX(I-1,J)+EX(I-1,J)+EX(I-1,J))-(FX(I-1,J)+EX(I-1,J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J)-VP1(I.J
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  ETAP1(I, J)=RETA(I, J)-(DELT*O.5)*ETAP1(I, J)
DP1(I,K)*D(I,K)-ETA(I,J)+ETAP1(I,J)
CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  10 93
                                                                                                                                                                                                                                                                                                                                                                              SUBROUTINE ETAS(RETA, DELT)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     ETAP1(I,N2)=ETAP1(I,3)
ETAP1(I,N1)=ETAP1(I,2)
ETAP1(I,1)=ETAP1(I,N)
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DP1(I,N1)=DP1(I,2)
DP1(I,1)=DP1(I,N)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                IF(DP1(I,1).GT.DD)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            DP1(I,K)=D(I,K)
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                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             DO 24 I=1, IDRY
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          DO 23 J=2,N1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     DO 60 I=1,M
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                DO 92 I=1,M
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C* SUBROUTINE UCALC(TD.TU,TV,DELT)  C* C* UCALC CALCULATES THE DEPTH AVERAGED VELOCITIES BASED ON THE  C* RESULTS OF SUBROUTINE MOMEN  C*	# # # # 	<pre>K=J-1 UP1(I,J)=((TD(I,K)+TD(I-1,K))*TU(I,J))/(DP1(I,K)+DP1(I-1, *K))-((DELT*2.0)/(DP1(I,K)+DP1(I-1,K)) VP1(I,J)=((TD(I,K)+TD(I,K-1))*TV(I,J))/(DP1(I,K)+ *VP1(I,J)=((TD(I,K)+TD(I,K-1))*TV(I,J))/(DP1(I,K)+ *VP1(I,J)=((TD(I,K)+TD(I,K-1))*VP1(I,J)) 24 CONTINUE DO 22 J=3,N1 DO 27 I=1,IWET UP1(I,J)=0.0 27 CONTINUE UP1(M,J)=0.0 VP1(M,J)=0.0 VP1(M,J) VP1(M,J)=0.0 VP1(M,J) VP1(M,J) VP1(M,J) VP1(M,J) VP1(M,J) VP1(M,J) VP1(M,J) VP1(M,J) VP1(M,J) VP</pre>	60 69 67 67 67 67 67 67 67 67 67 67 67 67 67	C*
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                           *H(50,50),CG(50,50),Y(50,50),HBREAK(50,50),IB(50,50),DDDX(50,50),

*DDDY(50,50),W(50,50),Y(50,50),HBREAK(50,50),IB(50,50),DDDX(50,50),

*COMMON/VAL/DP1(50,50),DM1(50,50),UP1(50,50),UM1(50,50),

*VP1(50,50),VM1(50,50),ETAP1(50,50),ETAM1(50,50),ETA(50,50),

*M.N.N.N.N.N.X.M.M.Z.M.DD.IT.RHG.IWET,IDRY,ID

DG 1 1=1,M

DG 1 J=1,N

ETAM1(1,J)=ETA(1,J)

ETA(1,J)=ETA(1,J)
                                                                                                                                                                                                                                                                                                                                                                                                                                                           COMMON D(50,50),U(50,50),V(50,50),Z(50,50),SI(50,50),CO(50,50),*H(50,50),CG(50,50),CG(50,50),RREAK(50,50),IB(50,50),DDDX(50,50),RDDY(50,50),W(50,50),V(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),W(50,50),ETAPY(50,50),UP1(50,50),ETAPY(50,50),COMMON/CONST/G,PI,PI2,RAPY(50,50),ETAMY(50,50),ETA(50,50),BD 20 J=2,N1
                 COMMON D(50,50),U(50,50),V(50,50),Z(50,50),S1(50,50),CD(50,50)
                                                                                                                                                                                                                                                                                                                                                                                                  CONTIN CALCULATES THE FINAL CORRECTION TO TOTAL DEPTH BASED ON THE EQUATION OF CONTINUITY
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        DO 20 I=IWET,M1

IF (K.Eq.1) GO TO 21

ETAP1(I.J)=(((D(I+1,K)+D(I,K))*U(I+1,J)-

*(D(I,K)+D(I-1,K))*U(I,J))/DX+((D(I,K+1)+D(I,K))*V(I,J+1)-

*(D(I,K)+D(I,K-1))*V(I,J))/DY)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     ETAP1(I,J)=(((D(1+1,K)+D(I,K))*U(I+1,J)-
*(D(I,K)+D(I-1,K))*U(I,J))/DX+((D(I,K+1)+D(I,K))*V(I,J+1)
*-(D(I,K)+D(I,N-1))*V(I,J))/DY)
                                                                                                                                                                                                                                                                                                                                                                     SUBROUTINE CONTIN
                                                                                                                                                                                     UM((1,J)=U(1,J)
U(1,J)=UP+(1,J)
V(1,J)=V(1,J)
V(1,J)=VP+(1,J)
D(1,J)=DP+(1,J)
DM+(1,J)=D(1,J)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        GO TO 20
                                                                                                                                                                                                                                                                                       CONTINUE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     20 CONTINUE
                                                                                                                                                                                                                                                                                                      RETURN
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     RETURN
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            K=U-1
                                                                                                                                          113400
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113800
113900
                                                                                                                                                                                                                                                      14 100
14 200
14 4 200
14 4 500
14 4 600
14 8 00
15 100
15 100
15 2 00
15 3 00
                                                               12900
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13200
13300
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